# A STUDY OF TIME VARIABILITY OF SURFACE CURRENTS AT A POINT IN MONTEREY BAY

Harry Marshall Howton

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# THESIS

A Study of Time Variability of Surface Currents

at a Point in Monterey Bay

by

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December 1972

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# A Study of Time Variability of Surface Currents at a Point in Monterey Bay

by

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ABSTRACT

The geomagnetic electrokinetograph (GEK) was used to measure surface currents near the center of Monterey Bay during six separate 24-hour periods from May through July, 1972. An average of 244 current vectors were derived for each cruise. The mean currents from these cruises are all southerly and ranged from 4.1 cm/sec to 20.4 cm/sec. The average of these mean currents is 12.1 cm/sec toward 163°T. These values were compared with individual currents derived from dynamic topographies from the same period.

Diurnal and semi-diurnal variations of the current were studied after subjecting the data to a fourier analysis. It was concluded that there must be at least an indirect coupling of the ocean currents with the semi-diurnal tide at the data point. The diurnal component also is important; it may be tidal or inertial, or merely related to the passage of the sun.

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# I. INTRODUCTION

I. INTRODUCTION

This study was designed to use the Geomagnetic Electrokinetograph (GEK) to investigate the time variability of surface currents at one point in Monterey Bay.

Recent studies by Smith (1971) and McKay (1970) utilized the GEK to measure surface currents, but these measurements were taken singly, over large areas, and at different times. In order to determine the nature of the surface currents in Monterey Bay it was necessary to get data which was independent of spacial changes and of a sufficiently long duration to show tidal and inertial effects. The technique followed was to continually run squares with the GEK for approximately 24 hours. The squares averaged 0.5 nautical miles on a side and were repeated about every 24 minutes. Electrode zeros and current components were computed cyclically around the square.

Six experiments were conducted between 10 May and 22 July, 1972 at a point near the center of Monterey Bay (36°46'N/122°01'W) in water 440 fathoms deep (Figure 1). The Naval Postgraduate School (NPS) research vessel ACANIA was used to tow the GEK array. Analysis of the data was facilitated by the use of the NPS IBM 360 computer. Causes of variability of surface currents were sought in tidal, wind, inertial, and seasonal effects.

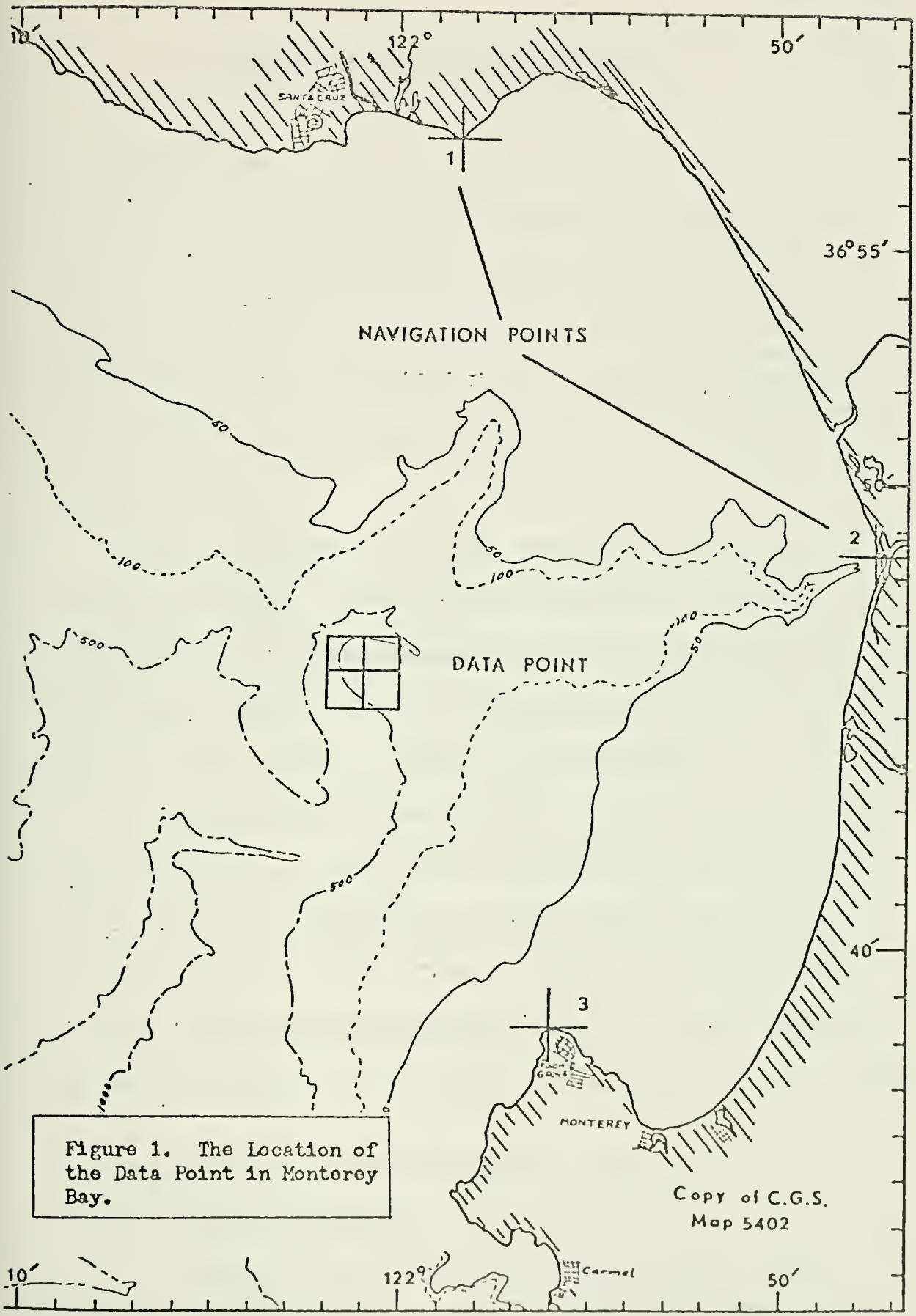


Figure 1. The Location of the Data Point in Monterey Bay.

## II. THE ELECTROMAGNETIC METHOD OF MEASURING OCEAN CURRENTS

### A. DEVELOPMENT

When a part of the ocean moves relative to the earth's magnetic field, a voltage is induced in the sea water. Under certain conditions a voltage equal to the induced voltage may be measured between two identical electrodes introduced into the sea. Under other conditions, part or all of the induced voltage is dissipated through resistance in the sea water.

Faraday is credited with the first mention of and experimentation with this phenomenon. His experiments failed; however, in the late 1800's broken trans-Atlantic cables showed the potential differences he had sought and led to the early 20th century experimentation in Dartmouth Harbor by Young, Gerrard, and Jevens (1920).

The electromagnetic method of towed electrodes is a continuation of this theory and is a result of work done between 1946 and 1954 by Longuet-Higgins and Barber (1946), Stommel (1948), von Arx (1950), and Longuet-Higgins, Stern, and Stommel (1954). The technique owes its name, Geomagnetic Electrokinetograph (GEK), to von Arx. Using the GEK method, surface currents can readily be measured from a ship underway.

### B. GEOMAGNETIC ELECTROKINETOGRAPH (GEK)

#### 1. Theory of Operation

The GEK is made up of a recording potentiometer, a two-conductor, neutrally buoyant cable, and a matched pair of silver-silver

chloride electrodes of the order of 100 meters apart. The potentiometer records the difference in potential between two electrodes. A long cable is required to allow the electrodes to be towed beyond the magnetic effects of the ship's steel hull.

An extensive discussion of electromagnetic theory and the ocean's movement through the earth's magnetic field may be found in von Arx (1950) and Longuet-Higgins, Stern, and Stommel (1954) (hereafter referred to as L-HSS). The following summary of L-HSS's treatment of this subject is by McKay (1970) with large portions of the development based on work by Curtin (1970).

The electrical field intensity along a conducting path that moves through a magnetic field is the difference between the two potential gradients. One potential gradient can be shown by application of Faraday's Law of Induction to be $\underline{V} \times \underline{H}$ as is done by L-HSS. In this expression, $\underline{V}$ is the vector velocity with which the conducting path is moved and $\underline{H}$ is the magnetic field intensity vector. The other potential gradient is given by Ohm's Law as $\rho \underline{i}$, where $\rho$ is the resistivity and $\underline{i}$ the electric current density vector along the conductor. If the potential is denoted $\Phi$, the negative of the electric force field in the moving conducting path can be expressed as

$$\nabla \Phi = (\underline{V} \times \underline{H}) - \rho \underline{i} \qquad (1)$$

When the electrodes are deployed, two distinct conducting paths are present: (a) the sea water, and (b) the long conductors to which the electrodes are attached. The potential in each of these paths is the

difference of the two terms of equation (1). In the following discussion, a right-hand co-ordinate system is utilized with the following conventions: the positive x-direction is that of the ship's head; y is the horizontal co-ordinate perpendicular to the course steered and z is positive up.

Consider first the sea water path. When the electrodes are towed directly astern of the ship, as shown in Figure 2, they sense the potential difference along a path parallel to the direction of the ship's head. The component of potential gradient generated in this direction due to the $(\underline{V} \times \underline{H})$ term is $(V_y H_z - V_z H_y)$, where $V_y$ is the component of water velocity perpendicular to the course steered (set of ship), $V_z$ is the vertical component of water velocity, $H_z$ is the vertical intensity of the earth's magnetic field, and $H_y$ is the horizontal intensity of the geomagnetic field in a direction perpendicular to the ship's course. If $V_z$ is assumed negligible in comparison with $V_y$, the measurable potential gradient generated by the water motion is $V_y H_z$; that is, the potential gradient contributed by the $(\underline{V} \times \underline{H})$ term is due to the component of water velocity perpendicular to the ship's course. This water motion causes the ship's set (and the set of the electrodes) and is independent of the ship's velocity in the direction of the interelectrode line. The second potential gradient in the sea water path, $\rho \underline{i}$, is a direct function of the electric current density along the path between the electrodes. The electric current density along this path depends on the electrical characteristics (potential gradient's resistances) of all other surrounding

paths, since it is only through the surrounding paths that a closed electric-current-carrying circuit can be completed.

Consider next the part of the closed conducting path formed by the two wires and the voltmeter. It can be seen, by application of reasoning identical to that used for the sea water path, that the velocity-induced potential gradient due to the $(\underline{V} \times \underline{H})$ term in equation (1) is again $V_y H_z$. The second potential gradient $\rho \underline{i}$, is essentially zero in this path due to the low resistance of the wire and the small current drawn.

The potential differences sensed by the voltmeter and continuously recorded as GEK data are those developed in the wires leading to the electrodes and in the sea water between the electrodes. Traversing this path, as shown in Figure 2, and adding the potentials yields the following:

$$E = (V_y H_z)\overline{AB} + (V_y H_z)\overline{BC} + [(-V_y H_z)\overline{CB} - (\rho i_n)\overline{CB}] + (-V_y H_z)\overline{BA} \quad (2)$$

where E is the emf per unit distance and A, B, and C are the points shown in Figure 2. The sumbol $\overline{AB}$ represents the distance between A and B. The term in brackets represents the potential gradient in the sea water between the electrodes; the remaining terms represent the induced emf in the indicated sections of the wire. Equation (2) reduces to:

$$E = (\rho i_x)\overline{CB} \quad (3)$$

where the direction is that of the electrode line, or, in the case of electrodes towed directly astern, the direction of the ship's head.

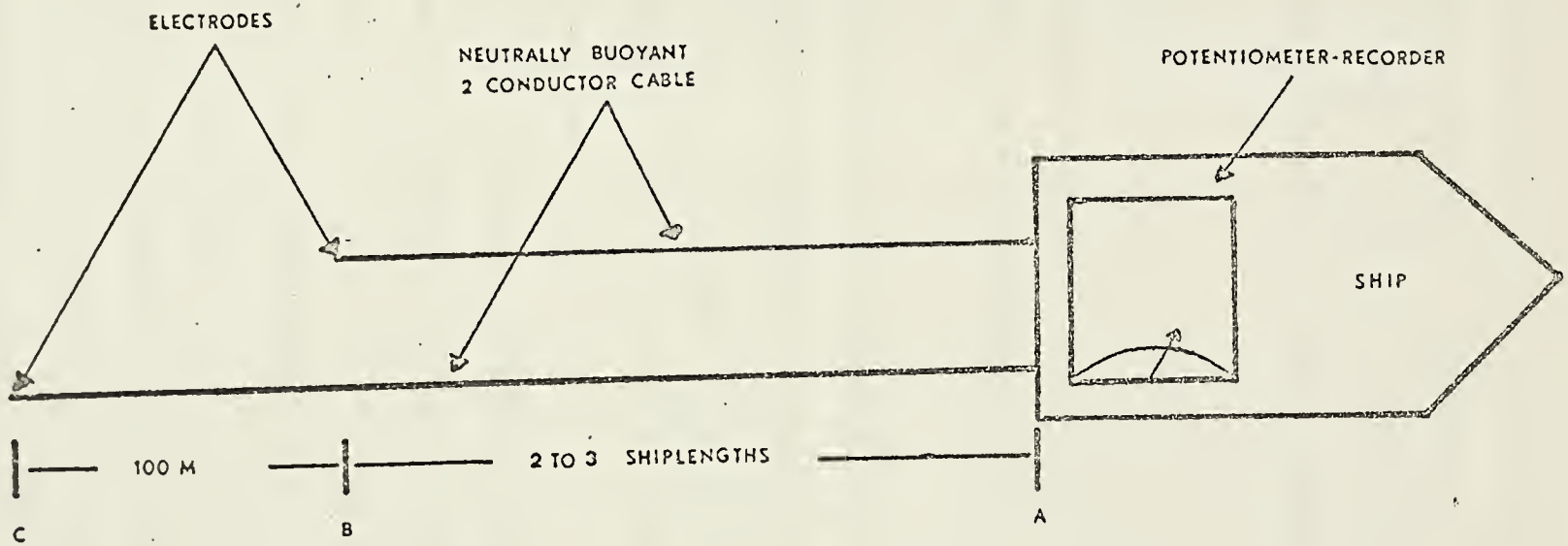


Figure 2. GEK COMPONENT ARRANGEMENT

For most currents in the deep ocean the potential gradient is completely short-circuited by the deep layer of relatively still water underlying the moving surface layer. In this case $\nabla \Phi = 0$ and $\rho \underline{i} = \underline{V} \times \underline{H}$. Under these conditions, if the interelectrode distance is s units, the horizontal potential difference measured by the voltmeter is:

$$E = (ksH_z V_h) \times 10^{-8} \qquad (4)$$

where $V_h$ is the horizontal component of water motion perpendicular to the interelectrode line and k is a constant near unity, to be discussed in Section III C.

The positive direction of E is taken as that of the ship's head and the current velocity is determined by adding the electric vectors, E, obtained on two courses, at right angles. The following example indicates the relationship between the direction of the current component measured and that of the interelectrode line:

> If $V_h$ is positive toward the east, $H_z$ is directed downward, and the interelectrode line is parallel with a meridian of longitude, E will have a positive polarity at the southern electrode and a negative polarity at the northern electrode.

Since $H_z$ is positive downward in the northern hemisphere, the following convention must be observed to obtain the true direction of the current velocity: In order that the deflection recorded by the instrument be in the same direction as the set of the electrodes, the conductor leading to the more distant electrode must be connected to

the voltmeter input terminal which, when made positive, gives a deflection of the recorder current indicator to the right. The necessity of observing this convention can be seen from the example given above. This convention must be reversed in the southern magnetic hemisphere, where $H_z$ is directed upward.

2. Assumptions

As has been stated above, the electric current density, $\underline{i}$, is a function of the conducting path in which it exists. Thus, with an assumption of uniform resistivity, the current density integrated along any line is directly dependent on the emf's in the available sea water paths surrounding that line. These emf's as indicated by Equation (1), are directly related to the water velocity in the region. Therefore, any electric current density measured at the surface is a reflection, in part, of the velocity field in the entire water column below the surface and in adjacent waters.

Recognition of this fact is essential for a meaningful interpretation of GEK data. It is only in the case of true oceanic currents that GEK data, unsupplemented by information derived from other sources, can be considered representative of the true surface current velocity. In this case the following conditions generally prevail:

(i) the vertical component of water velocity is negligible in comparison with the horizontal component,

(ii) the flow is broad compared with the depth of the water,

(iii) the current is steady in the x-direction, while a current "fix" is being obtained,

(iv) a deep layer of still water underlies the moving surface layer.

If condition (iv) is not obtained, the voltage is usually less than the theoretical and it is customary to multiply by a correction factor k determined by a simultaneous measurement with a current meter.

## III. EQUIPMENT

### A. ELECTRODES

A complete operating assemblage of GEK equipment was inherited from Smith (1971) at the onset of this project.

The matched set of silver-silver chloride electrodes was supplied by Woods Hole Oceanographic Institute and attached to the cable 100 meters apart by direct soldering. Von Arx (1950) describes the process by which electrode pairs are matched. The electrodes were padded and housed in a water permeable tube as shown by Smith (1971).

During the three-month period of data collection, it was not necessary to change the electrode installation.

To eliminate the electrochemical potential, the "zero point" must be obtained and subtracted out of the actual current vectors. This is normally done by reversing the electrodes end for end. In this case, the ship used a square sailing plan and the zero point was taken from opposite sides of each square. This is described in detail in Section V A.

### B. CABLE

A neutrally buoyant cable (Type B-3088) 329 meters long, made by the Vector Cable Company, was utilized during this investigation. The cable's function is to transmit to the recorder the electrode-generated signals from far enough astern (1.5 - 3.0 shiplengths) of the ship that the electrodes are not affected by the ship's magnetic field and wake.

## C. RECORDING POTENTIOMETER

The Geomagnetic Electrokinetograph Model V recording potentiometer based on a Speedomax Type G recorder was used to record the potential differences delivered from the electrodes by the cable. A photograph and a thorough description of the operation of the GEK Model V is contained in H. O. Publication 607.

The vertical intensity of the earth's magnetic field in gauss for the ship's location was taken from H. O. Chart Number 1702 and the rounded value was set into the recorder to the nearest tenth. A multiplication factor was later used to adjust the data to the exact magnetic vertical intensity at the data point. The multiplier includes compensation for annual variation, and is the ratio of the rounded vertical intensity to the correct local magnetic intensity. In this instance it was 0.91 (0.40/0.44).

As noted by Smith (1971) it is essential to isolate the power for the recorder from the ship's ground. This is done with an isolation transformer which must not be by-passed by the ground lead of a 3-wire power cord. Hence, a conventional two-prong plug is necessary.

The recorder also requires a signal multiplier setting. This k value is the ratio of the water speed observed by a non-electromagnetic method to the water speed measured by the electromagnetic method. An open ocean value of 1.04 is suggested by von Arx (1950) with the caution that higher values might be needed in areas where tidal currents and water shear occur.

The k factor was set at 1.10, following the recommendation of H. O. Publication 607 (1970 Ch. 1) for water deeper than 75 fathoms. This factor was derived from experience in open ocean conditions along the Atlantic coast. An unusual structure like Monterey Canyon may behave anomalously, a possibility which will be considered in the discussion of accuracy (Section V D). An incorrect choice of k does not lead to an error in direction.

## IV. SHIP PROCEDURES

### A. PLATFORM

The research vessel ACANIA was acquired by the Naval Postgraduate School in 1971 and refitted as an oceanographic research vessel. She was launched in 1929 and for many years took part in research activities under the Stanford Research Foundation.

R/V ACANIA's length is 126 feet, maximum speed is ten knots, and she carries a crew of five. Of the standard equipment aboard ACANIA, the Decca RM 416 radar was the most important to this study as noted in Section IV C. The UQN - 1 depth finder was also used briefly to confirm charted depths at the data point.

### B. SAILING PLAN

Both clockwise and counterclockwise squares were traversed during the cruise series, allowing the ship to remain within 1000 meters of the data point in calm weather and within 1500 meters during heavier weather.

Ship's speed was held at five knots for all cruises, but the time on each leg was varied between four and nine minutes, depending upon wind and current conditions. In order to maintain position within 1000 meters of the data point the downwind leg might take four minutes, while the upwind leg (opposite side of the square) might take eight minutes. All legs were at least four minutes long to insure that the cable had straightened out and a good signal was being received.

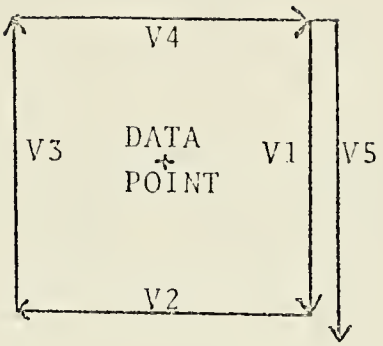


FIGURE 3. SAILING PLAN AND COMPONENT COMPUTATION

FIRST VECTOR:

$$\text{ZERO} = \frac{V1 + V3}{2}$$

E-W COMPONENT = V1-ZERO
N-S COMPONENT = V2-ZERO

$$\text{CURRENT MAGNITUDE} = \left[ (E-W)^2 + (N-S)^2 \right]^{1/2}$$

$$\text{CURRENT DIRECTION} = \arcsin \frac{E-W}{MAGN}$$

SECOND VECTOR:

$$\text{ZERO} = \frac{V2 + V4}{2}$$

E-W COMPONENT = V3-ZERO
N-S COMPONENT = V2-ZERO

THIRD VECTOR:

$$\text{ZERO} = \frac{V3 + V5}{2}$$

E-W COMPONENT = V3-ZERO
N-S COMPONENT = V4-ZERO

Only cardinal headings were steered during this series of cruises. The sailing plan is shown in Figure 3.

## C. NAVIGATION

The data point for this project was located close to the center of Monterey Bay over the Canyon. Navigation was by radar at ranges of roughly 11 miles from well-defined landmarks. These points are noted on Figure 1. Visual bearings were also used to augment the radar range information. The positioning accuracy is estimated to be $\pm$ 0.1 nm.

## V. DATA COLLECTION, REDUCTION, AND PRESENTATION

### A. SURFACE CURRENTS

#### 1. Data Collection

During each cruise approximately twenty-four hours of consecutive surface current readings were obtained. All data was taken at one point near the center of both Monterey Bay and the Monterey Canyon. An average of 244 current vectors were obtained from each of the six cruises.

The GEK recording potentiometer was continuously manned in order that the strip chart could be annotated and the potentials logged for each leg of the sailing plan. The ship's speed was five knots with each leg of the square being between four and nine minutes in duration. The average duration was six minutes. Longer and shorter legs were run to compensate for the ship's drift.

The primary items logged on the data sheet were: ship's heading (°T), velocity (cm/sec), and time. Weather, position, depth, speed, and other pertinent data were also logged on each data sheet.

The strip chart was marked and the time was noted for each change of course. The date, segment of cruise and cruise number were also recorded on the chart.

Breaks in the data of about ten to fifteen minutes occurred when the direction sailed around the square was changed from clockwise to counterclockwise or vice versa. Several breaks in the data sets of up to forty-five minutes occurred due to steering casualties.

2. Data Reduction

The IBM 360/67 computer at the Naval Postgraduate School computer center was used to reduce the rough data to current magnitudes and directions.

As can be seen from Figure 3, there is an interdependence of current vectors in each square since one of the current vector components is calculated from a leg of the square which will take part in the next zero computation. This procedure allowed for the calculation of approximately ten current vectors per hour.

The outputs of the data reduction computer program included east-west (E-W) and north-south (N-S) components, time, and the magnitude and direction of each current vector. This computer program is listed in Appendix A with suitable comments and explanations. Appendix B lists sample current data for Cruise I.

Sharply alternating speeds were present in the data after reduction. These variations were removed by averaging alternate pairs of data. A full discussion of these variations is to be found in Section V D.

3. Data Presentation

To produce a clear presentation of current magnitudes versus winds and tides, a computer program was written which utilized the plotting package for the CALCOMP Model 765 plotting equipment along with the IBM 360 computer.

For each cruise this graphing program produced the plots of E-W and N-S components and resultants versus time. Corresponding tide heights and wind speeds were plotted on the same graph. Northerly and easterly sets were taken to be positive. Both unaveraged and averaged data were handled in this fashion. The graphing program is included after the reduction program in Appendix A.

The data is also presented in a progressive vector diagram format for each cruise. The progressive vector diagram again utilized the plotting package and may be found with explanations in Appendix A.

## B. WINDS

Estimations of wind speed and direction were recorded aboard R/V ACANIA at various times (normally every two or three hours) during each cruise. These estimates were compared with the hourly readings logged at the U. S. Coast Guard lighthouse on Point Pinos. A composite of these two sources forms the basis for the wind magnitude and direction utilized for each cruise. Appendix C contains the resulting hourly wind data for Cruise I.

## C. TIDES

Tide records from Pier Number 1 at Monterey were made available by the NPS Oceanographic Department. This data was used to plot directly the tidal curve for each cruise. These tides compare favorably with the high and low tidal heights as calculated from the U. S. Coast and Geodetic Survey Tide Tables. The hourly tidal heights utilized are contained in Appendix D.

A tide prediction computer program was also written, based on harmonic constants for San Francisco and corrected to the data point in Monterey Bay. The results from this effort did not correlate well with either the tide gauge measurements or the tide tables, and were, therefore, not considered further.

## D. DISCUSSION OF ACCURACY

In discussing the accuracy of the current data the following potential errors must be considered:

(i) Errors in the observed voltage due either to reading inaccuracies or to the failure of the trace to steady to a constant value after a turn.

(ii) Errors due to inadequate depth or effects of the canyon walls not compensated for by the k factor.

(iii) Errors due to substantial velocity gradients across the square.

Since the trace could be read to $\pm$ 1 cm/sec, and at least four minutes were always given to steady out this trace, the errors in Group (i) are small. They are not systematic and in the long term average to zero.

It is not known how great the errors of Group (ii) may be. There may not be a thick layer of static water near the bottom (current shears, internal waves may exist) and the lateral dimensions of the parcel of deep water are relatively small. Because of the sharply sloping walls

of the canyon, bottom effects may affect different legs unequally and cause aberrations. In these circumstances it is unwise to be categorical about the adequacy of using k = 1.10. On the other hand, the speeds measured are plausible and not notably at variance with the few available measurements obtained in various locations in Monterey Bay.

The sharply alternating speeds described in Section V A 2 may best be explained by the existence of large velocity gradients across the square. These gradients may be caused by variations of depth or by actual currents or eddies. This is contrary to the assumption that the current is broad and therefore the same on both sides of the sailing plan. This breakdown, coupled with the circular and redundant method by which the currents were computed, produces oscillations in a sequence high-medium-low-medium-high in the N-S and E-W components of current and in the resultant. (See Appendix C for an example.) If the current component actually present on one N-S leg has a magnitude E and on the opposite side has the magnitude E + $\triangle$ E, and likewise the remaining two sides of the square have magnitudes N and N + $\triangle$ N, then it may be shown that the peak-to-peak range of the resulting zig-zag will be the absolute value of $\triangle$ E - $\triangle$ N. (See Figure 3 for method of computation.) A maximum peak-to-peak range of 60 cm/sec occurs in the E-W component of Cruise I, though most peak-to-peak variations are of the order of 30 cm/sec. These variations were mostly removed from the data by averaging alternate pairs of values. Variations after averaging are of the order of 5 cm/sec. The process of averaging

alternate pairs would produce a speed corresponding to some point within the square, if the first explanation of the alternation is valid. It can be seen from comparing the graphs of averaged and unaveraged data, in Section VI and Appendix C, that the averaging process produces a plausible, smoothly varying curve.

# VI. ANALYSIS OF CURRENT DATA

## A. INTRODUCTION

Various presentations were used to show different aspects of the current data, and to correlate this data with winds, tides, and ocean currents. A summary of results of the fourier analysis with mean current values and a table of contemporary current data are included in this chapter (Tables I and II).

The graphical presentations are contained in Section B of this chapter in the following order:

(i) East-west current component versus wind and tide.

(ii) North-south current component versus wind and tide.

(iii) Total current magnitude versus wind and tide.

(iv) Progressive vector diagram with the cumulative transport past the data point marked every five "fixes" (approximately 30 minutes) with a cross.

Each set of graphs is prefaced with a short summary of sea and weather conditions for that particular period.

B. GRAPHICAL PRESENTATION OF DATA BY CRUISE

1. Cruise I

Period: 10 - 11 May 1972

Latitude: 36°46' N

Longitude: 122°01' W

Depth: 440 fathoms

Ship's Speed: 5 knots

Sea and Weather: Winds were from the WNW during this cruise, with a diurnal variation in wind speed caused partly by a land-sea breeze pattern. Velocities of up to 22 knots occurred in the late afternoon and virtual calm prevailed in the early morning hours. Seas varied from 0.5 to 2.0 feet with the wind velocity, while the swell was between 3 feet in the early morning and 8 feet in the early evening. Both were from the WNW. The sky was partly cloudy. Note that only the averaged current data is presented in this section. The unaveraged current data is presented in Appendix C. The start of the progressive vector diagram is labelled "S" and the end is labelled "E".

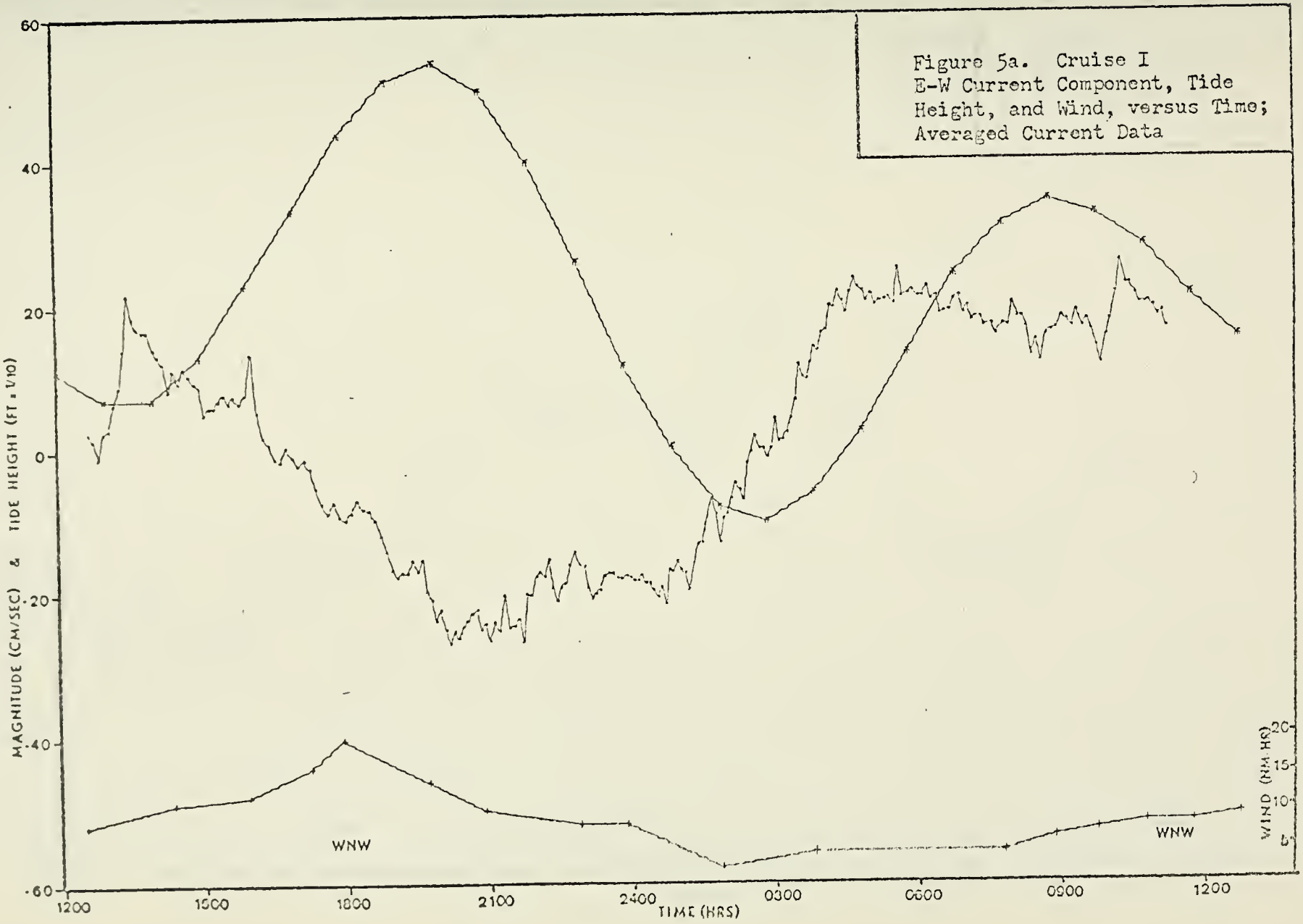


Figure 5a. Cruise I
E-W Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

Figure 5b. Cruise I
N-S Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

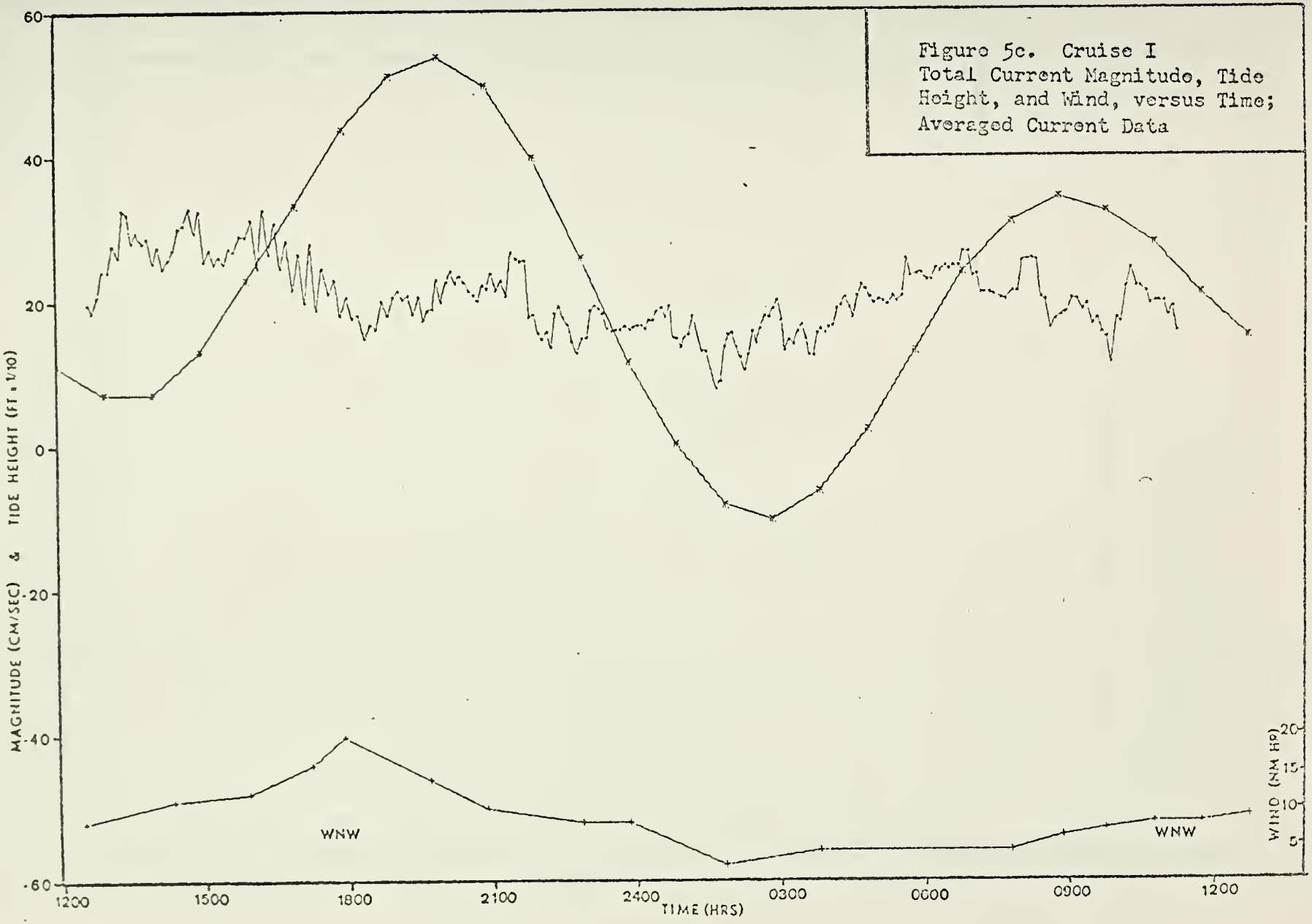


Figure 5c. Cruise I
Total Current Magnitude, Tide Height, and Wind, versus Time; Averaged Current Data

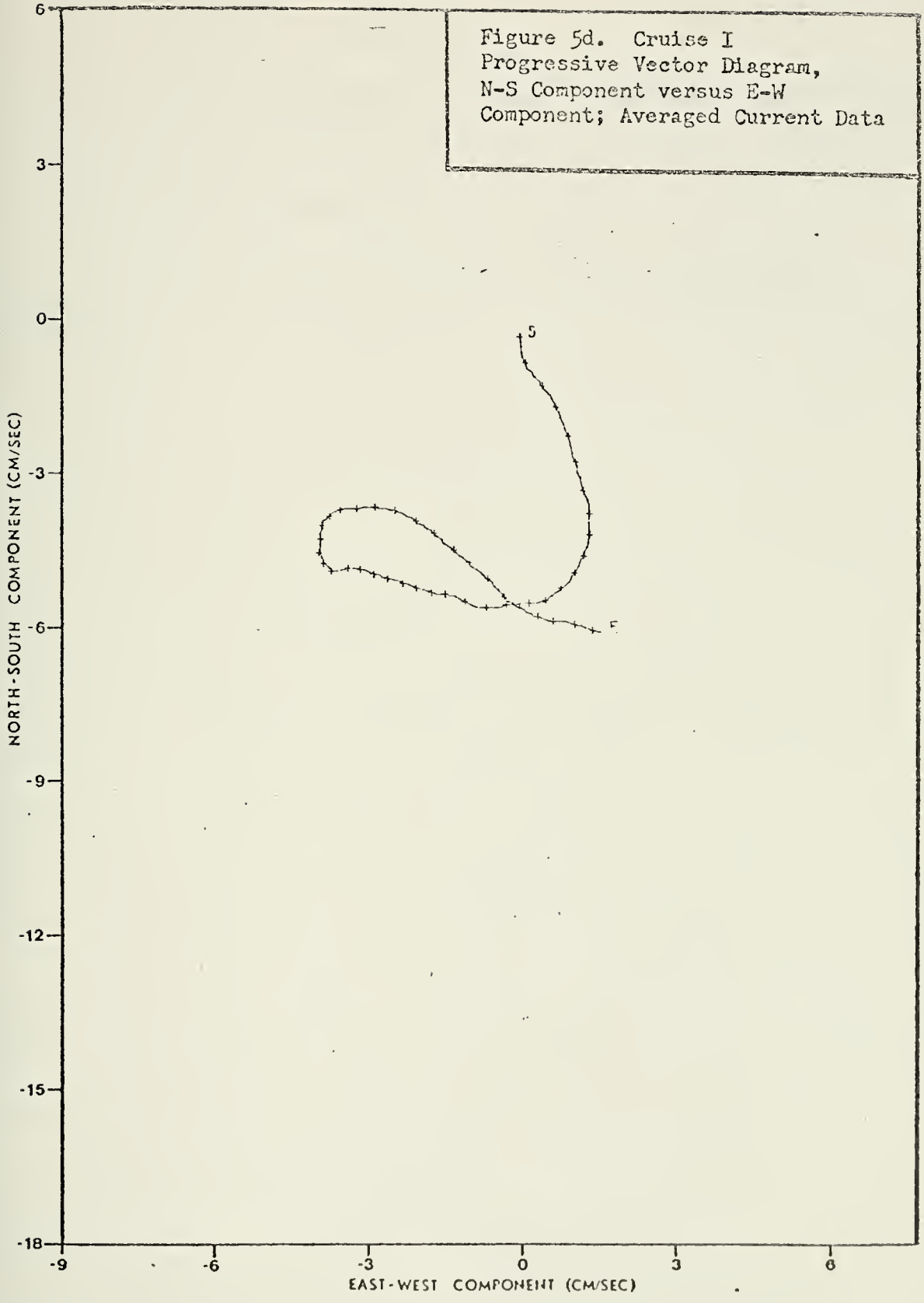


Figure 5d. Cruise I
Progressive Vector Diagram,
N-S Component versus E-W
Component; Averaged Current Data

2. Cruise II

Period: 30 - 31 May 1972

Sea and Weather: Same pattern and magnitude as in Cruise I, but with fog and overcast skies in the morning, clearing by mid-afternoon.

Note: All other information is the same as for Cruise I.

Figure 6a. Cruise II
E-W Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

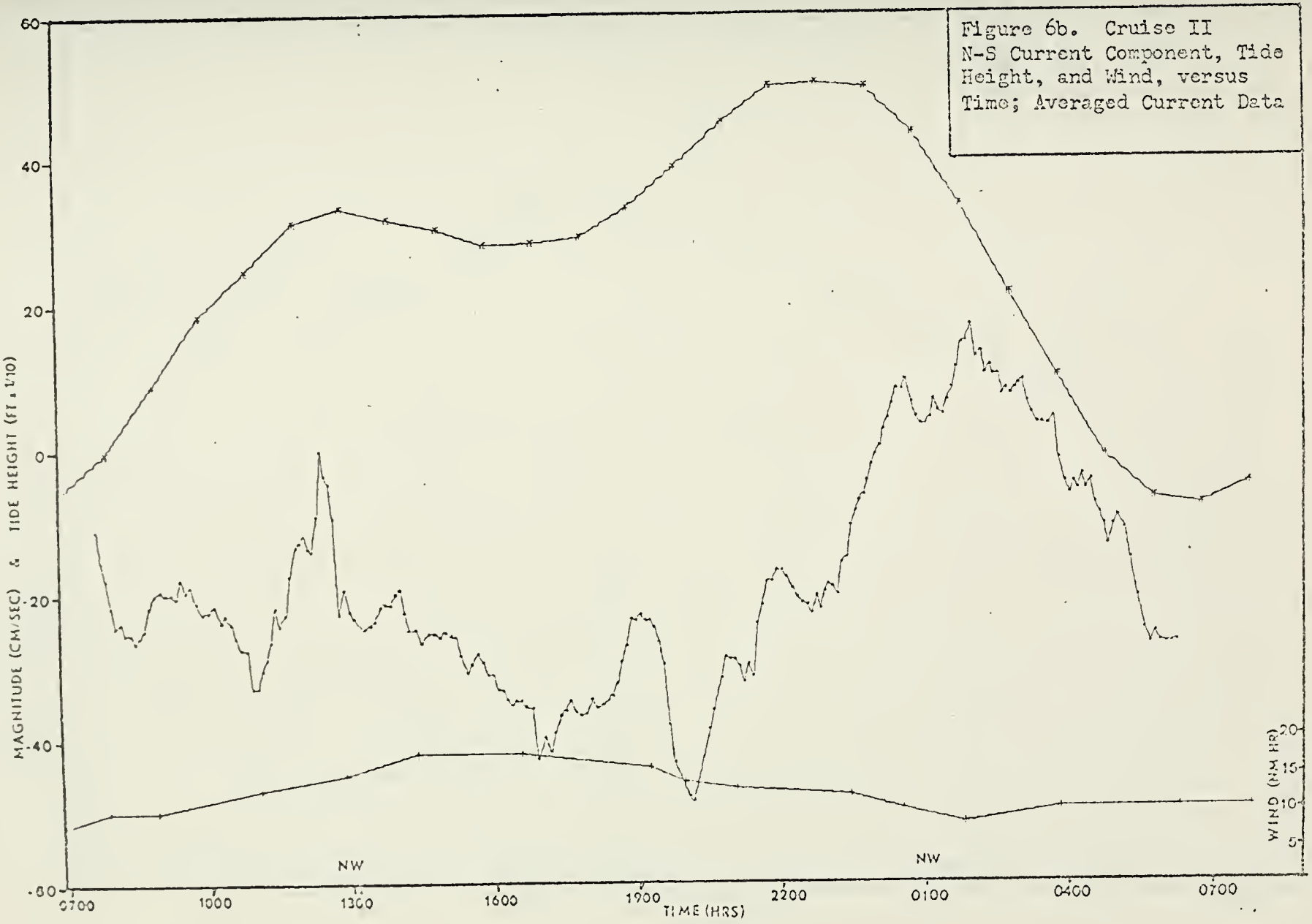


Figure 6b. Cruise II
N-S Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

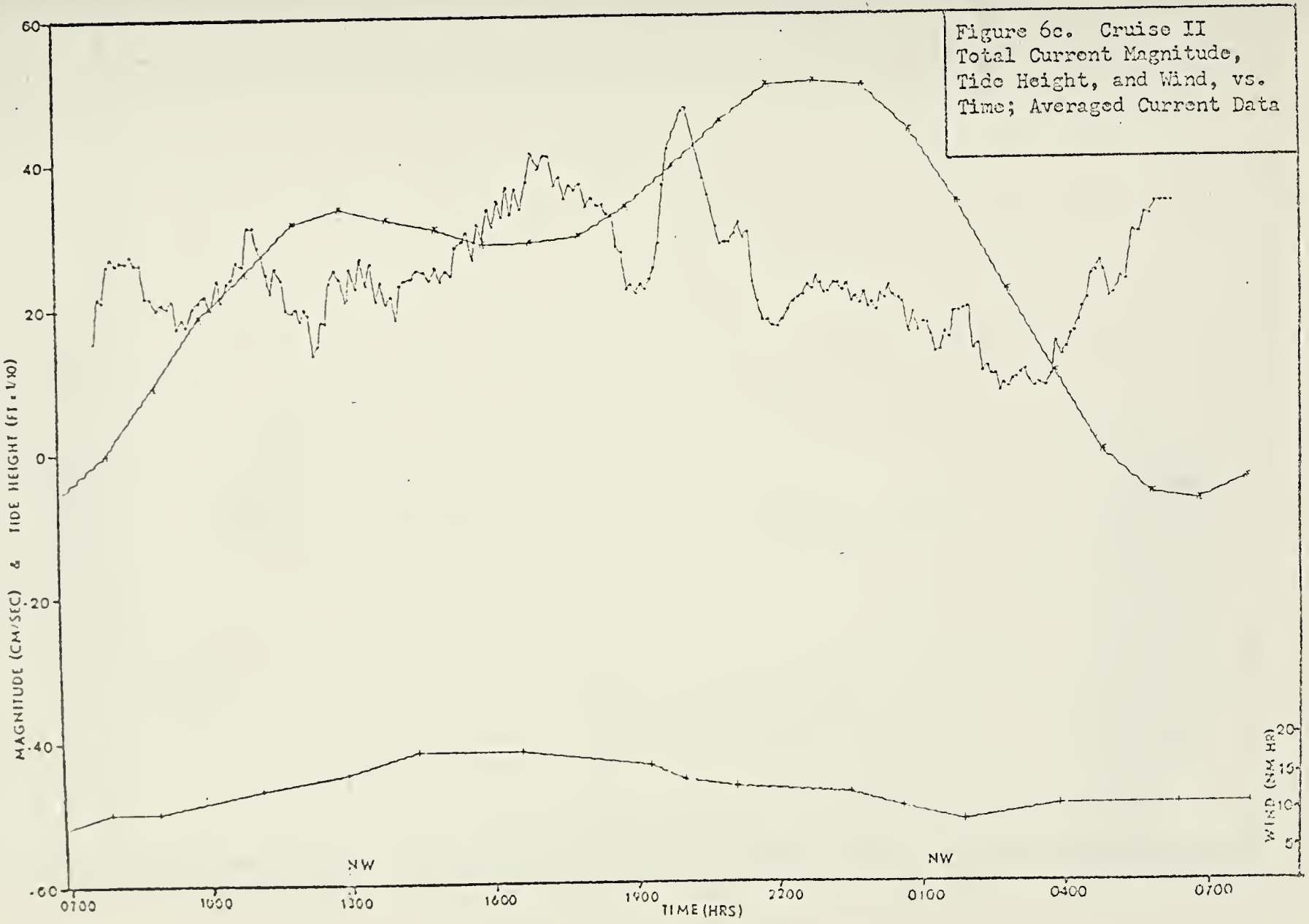


Figure 6c. Cruise II
Total Current Magnitude, Tide Height, and Wind, vs. Time; Averaged Current Data

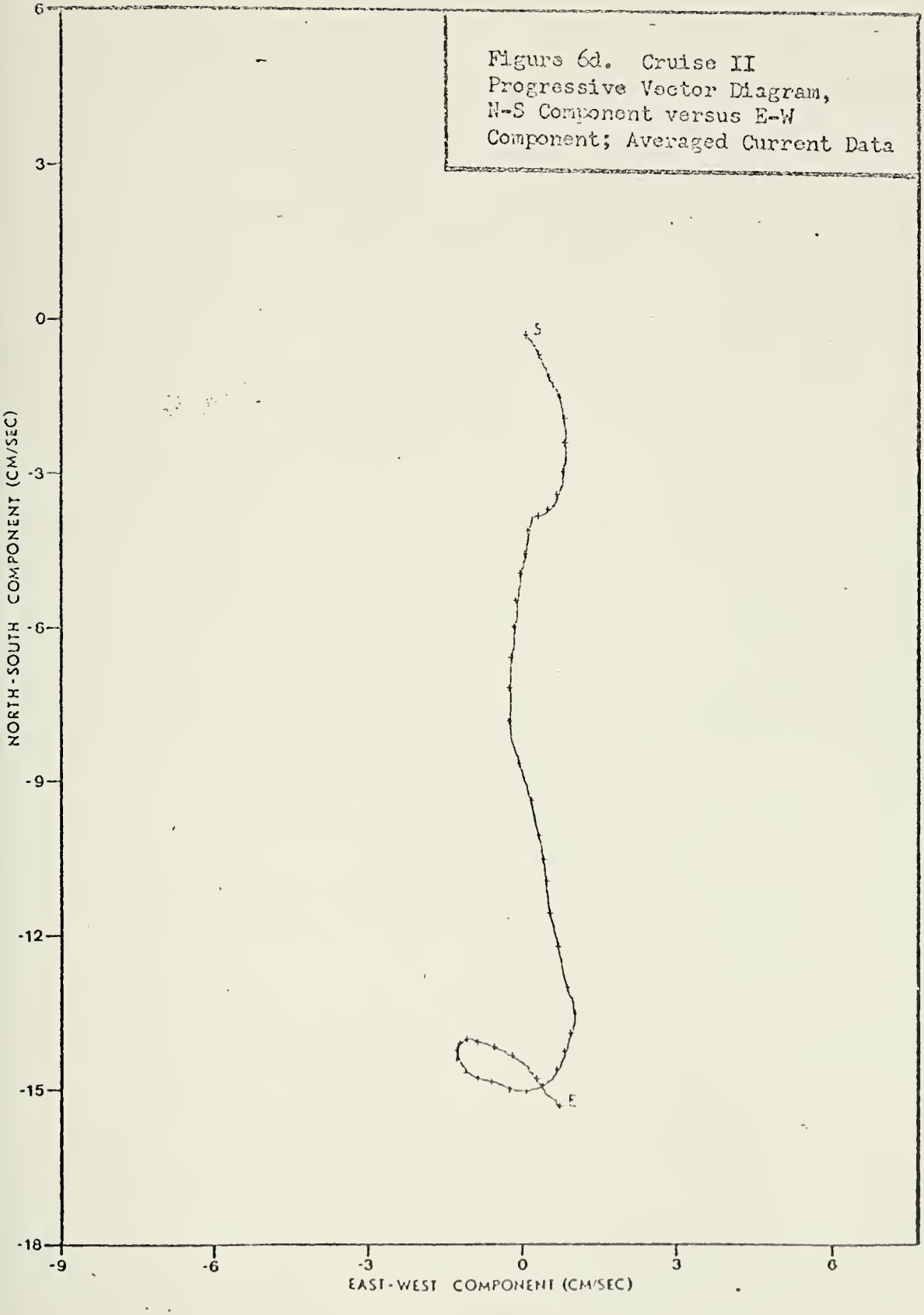


Figure 6d. Cruise II
Progressive Vector Diagram,
N-S Component versus E-W
Component; Averaged Current Data

3. Cruise III

Period: 19 - 20 June 1972

Sea and Weather: Weak and variable winds with a maximum velocity of 8 knots were the rule, with a 1 foot sea and 3 foot swell throughout the cruise. The sky was overcast and some drizzle fell in the morning.

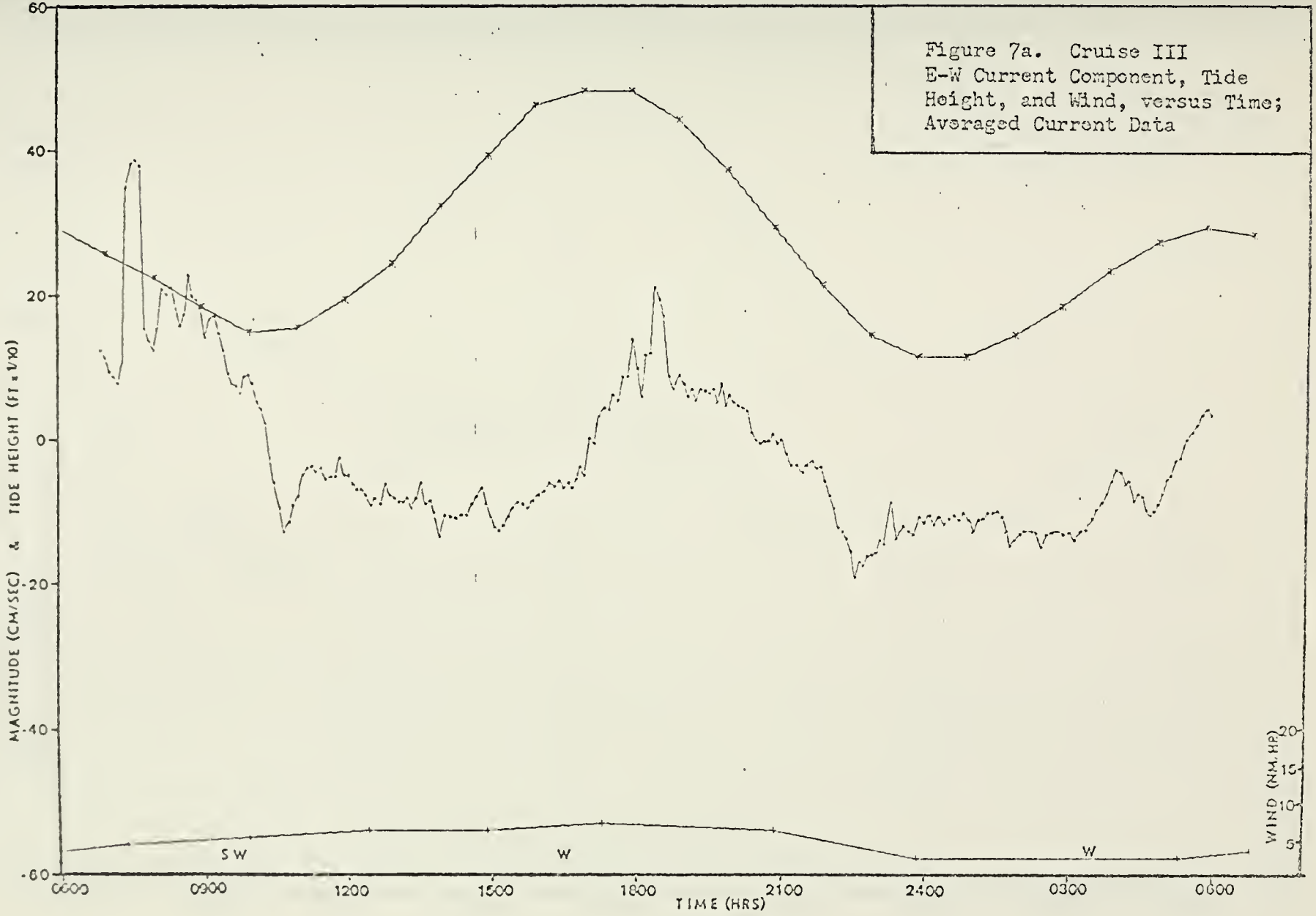


Figure 7a. Cruise III
E-W Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

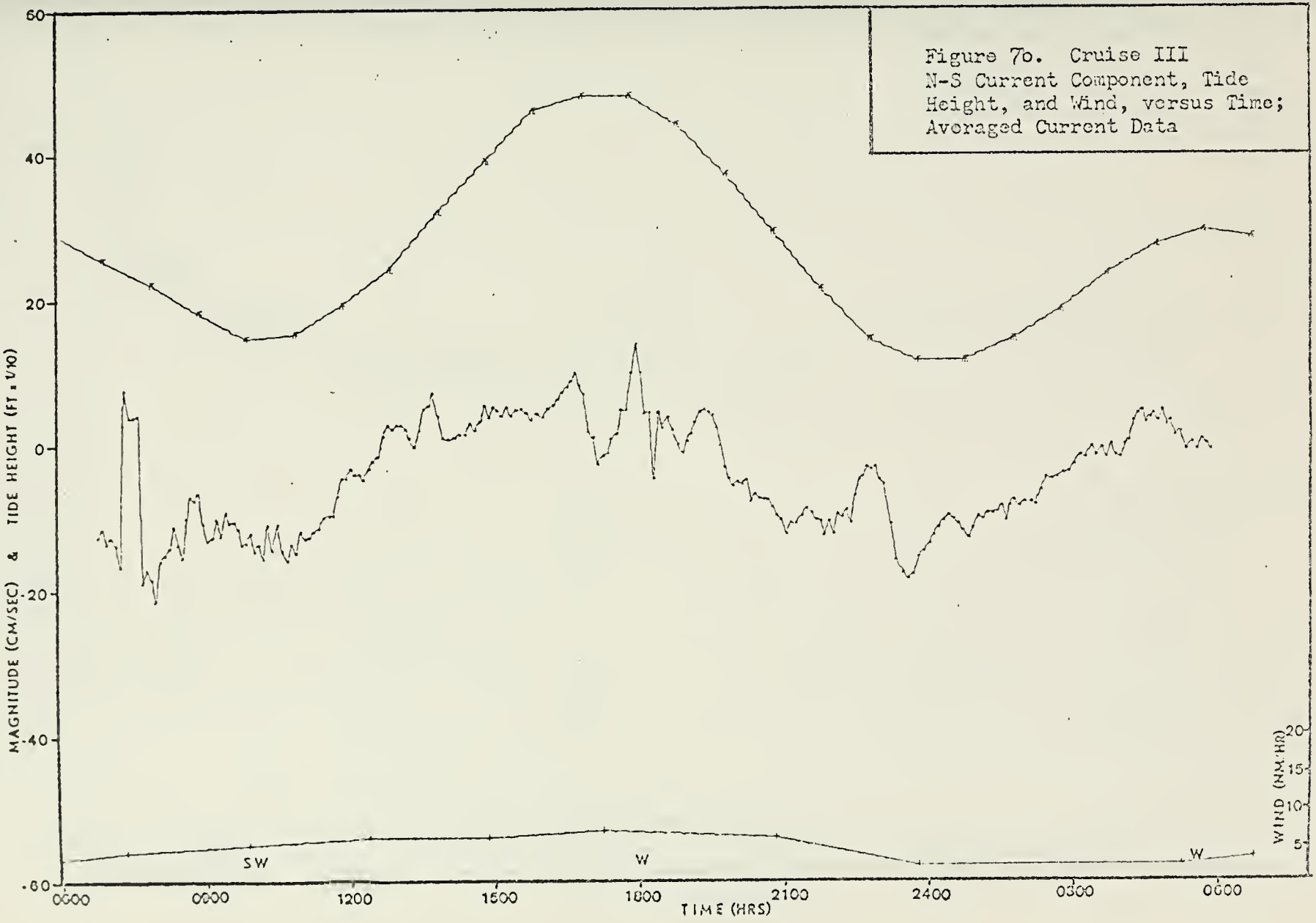


Figure 7o. Cruise III
N-S Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

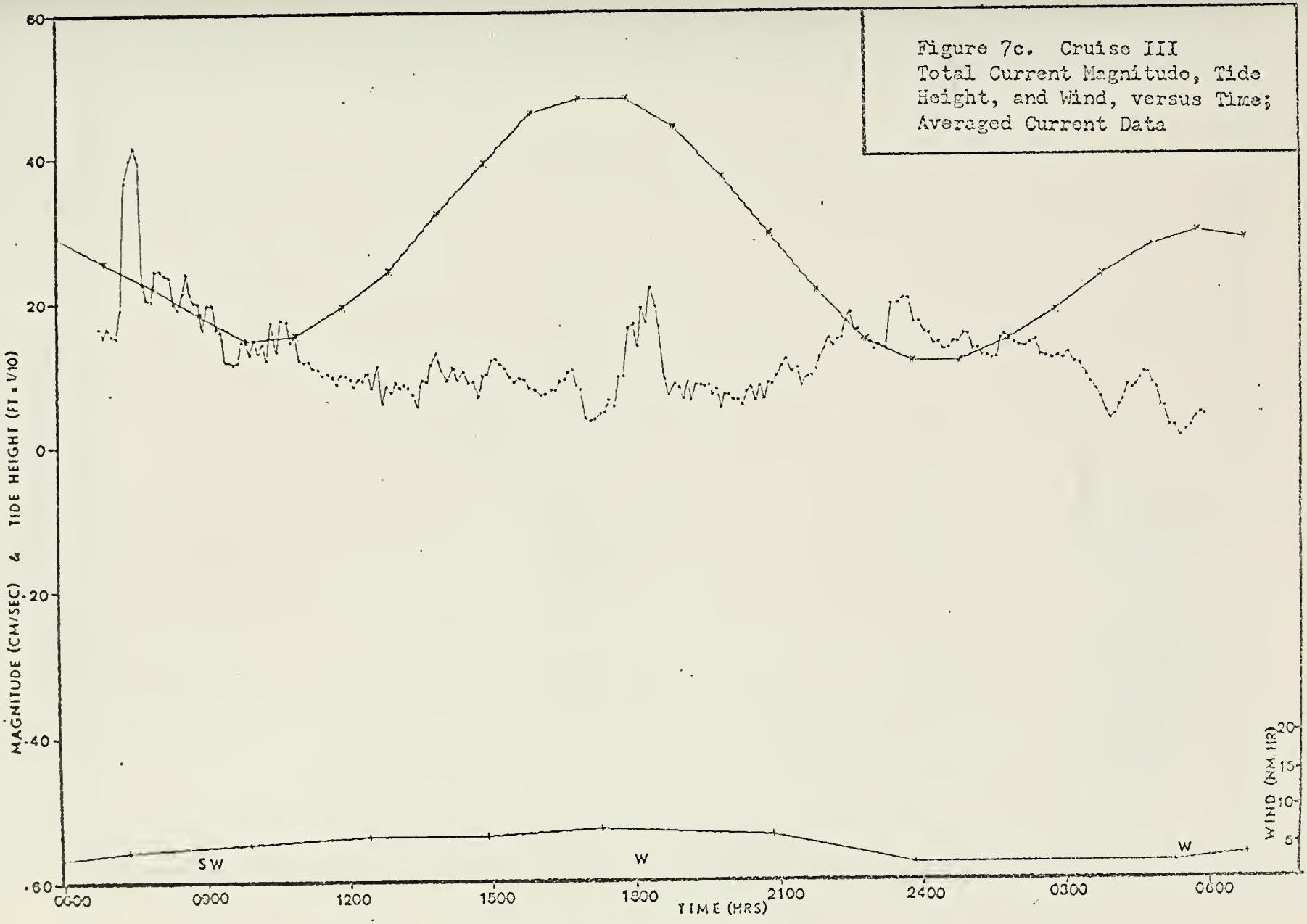


Figure 7c. Cruise III
Total Current Magnitude, Tide Height, and Wind, versus Time; Averaged Current Data

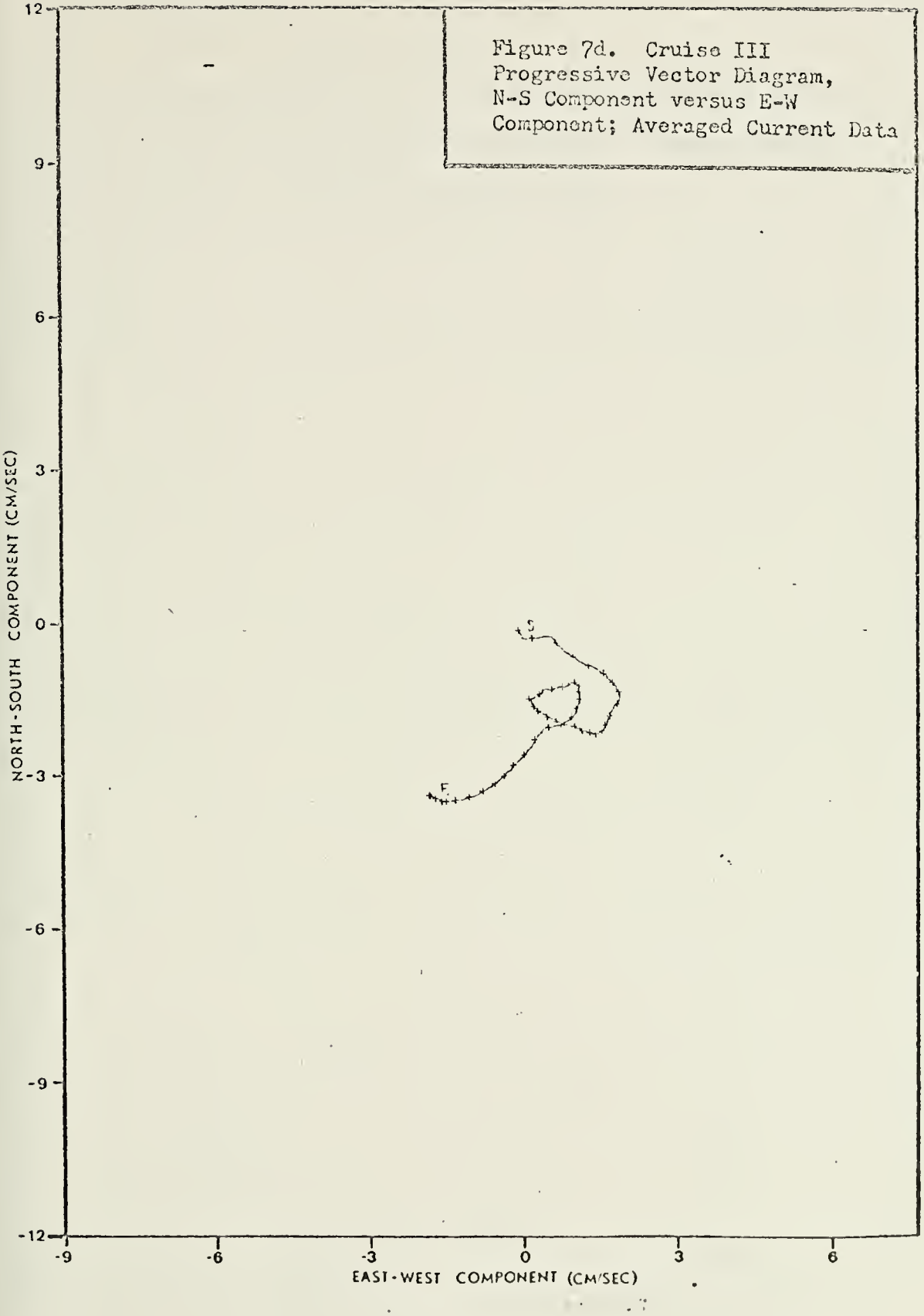


Figure 7d. Cruise III
Progressive Vector Diagram,
N-S Component versus E-W
Component; Averaged Current Data

4. Cruise IV

Period: 22 - 23 June 1972

Sea and Weather: Very similar to Cruise I with a maximum wind of 16 knots and overcast skies. Winds varied from west to southwest during this period.

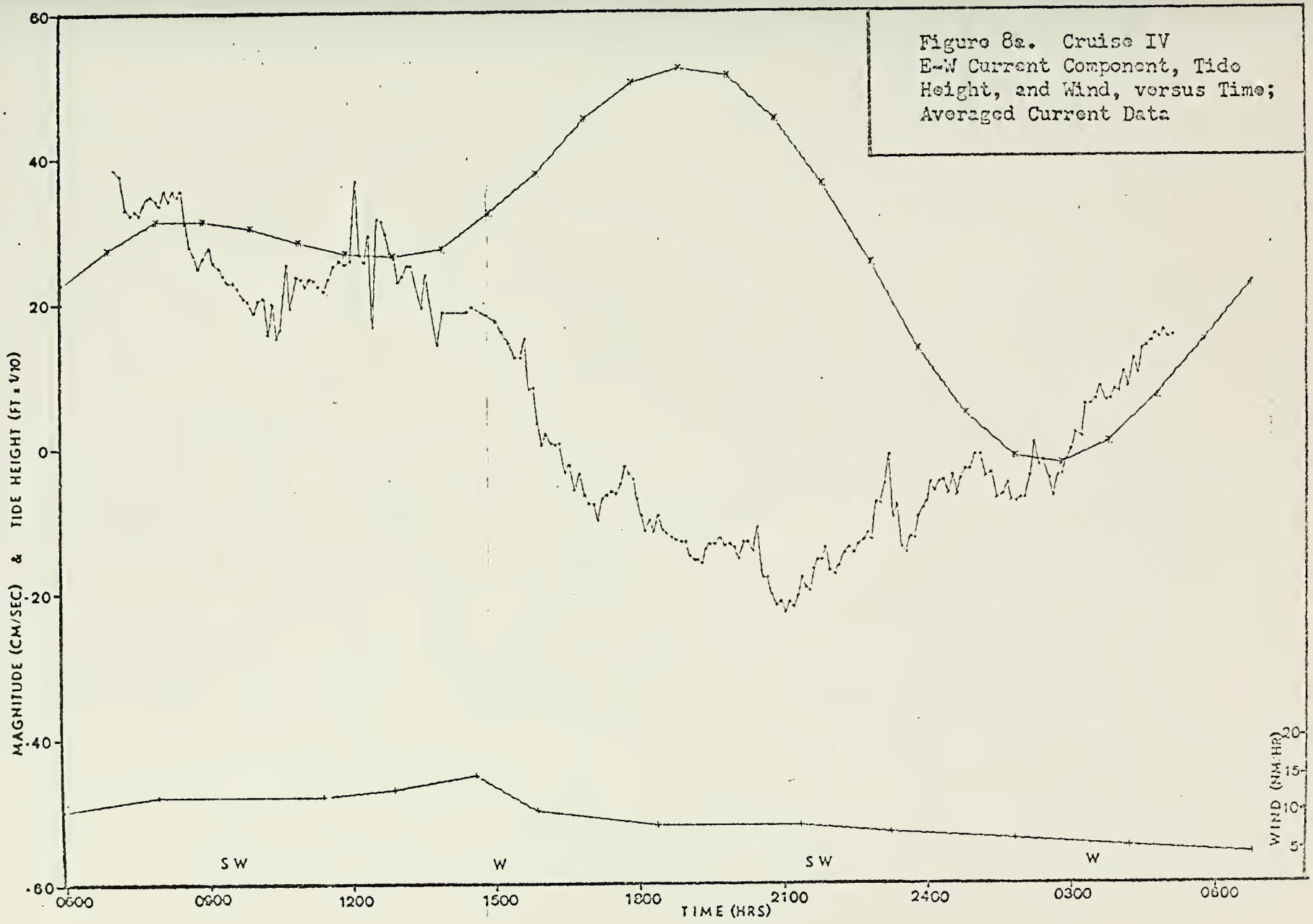


Figure 8a. Cruise IV
E-W Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

Figure 8b. Cruise IV
N-S Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

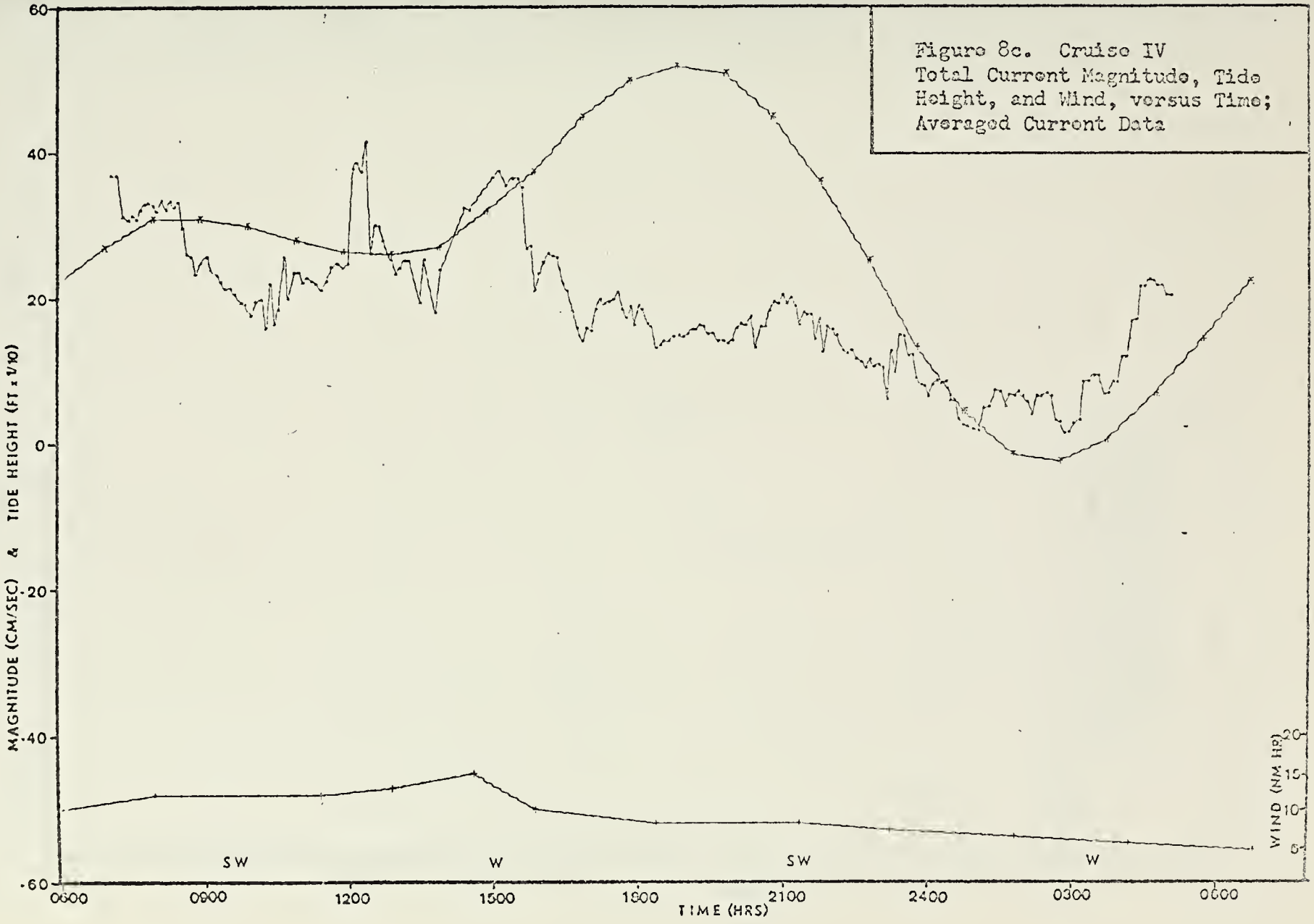


Figure 8c. Cruise IV
Total Current Magnitude, Tide Height, and Wind, versus Time; Averaged Current Data

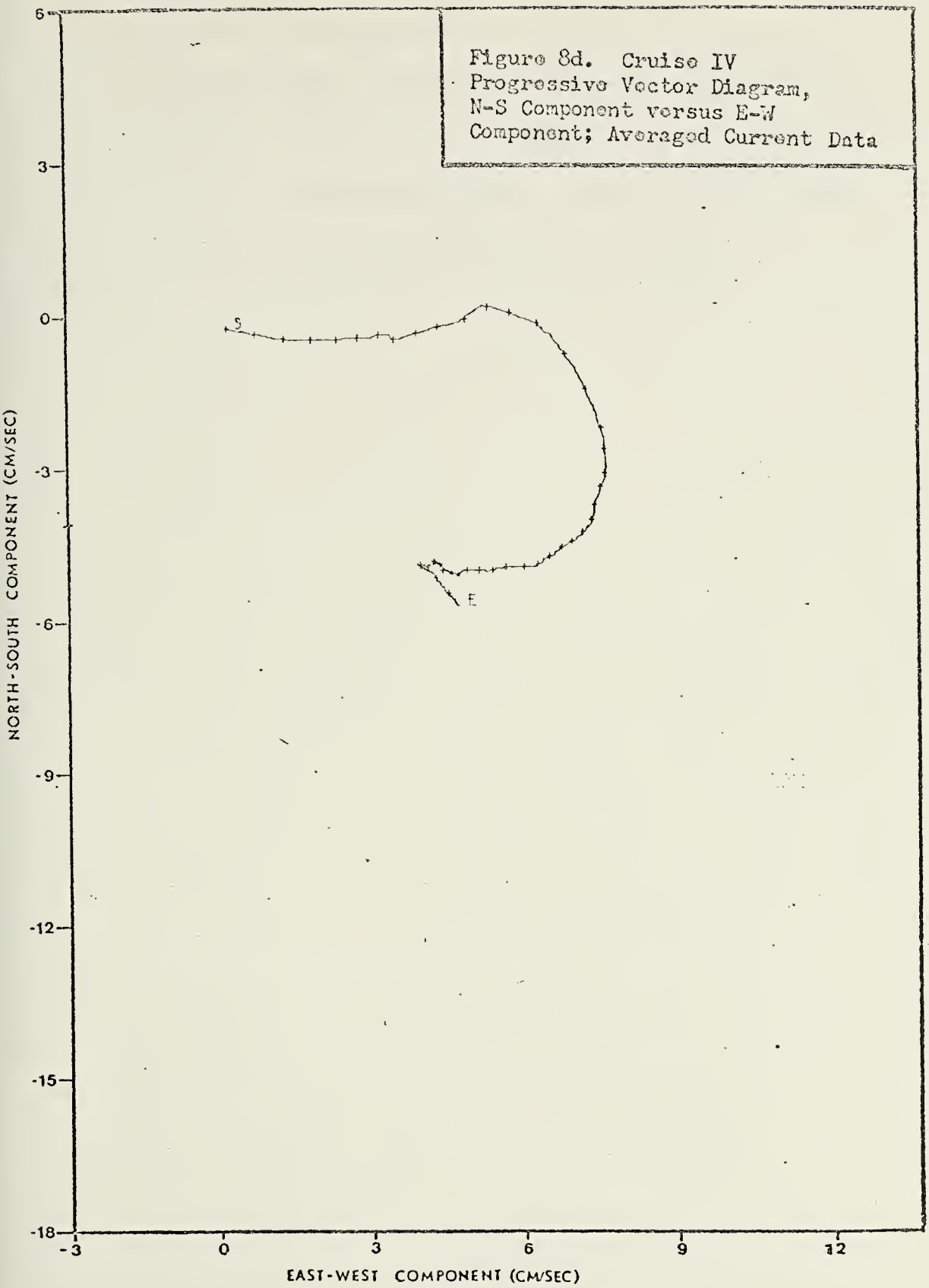


Figure 8d. Cruise IV
Progressive Vector Diagram,
N-S Component versus E-W
Component; Averaged Current Data

5. Cruise V

Period: 10 - 11 July 1972

Sea and Weather: Wind was fairly steady from the west to northwest at 5 to 18 knots with the same diurnal pattern as Cruise I. The skies were clear. Seas and swell were from the WNW with the same magnitude as Cruise I.

Figure 9a. Cruise V
E-W Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

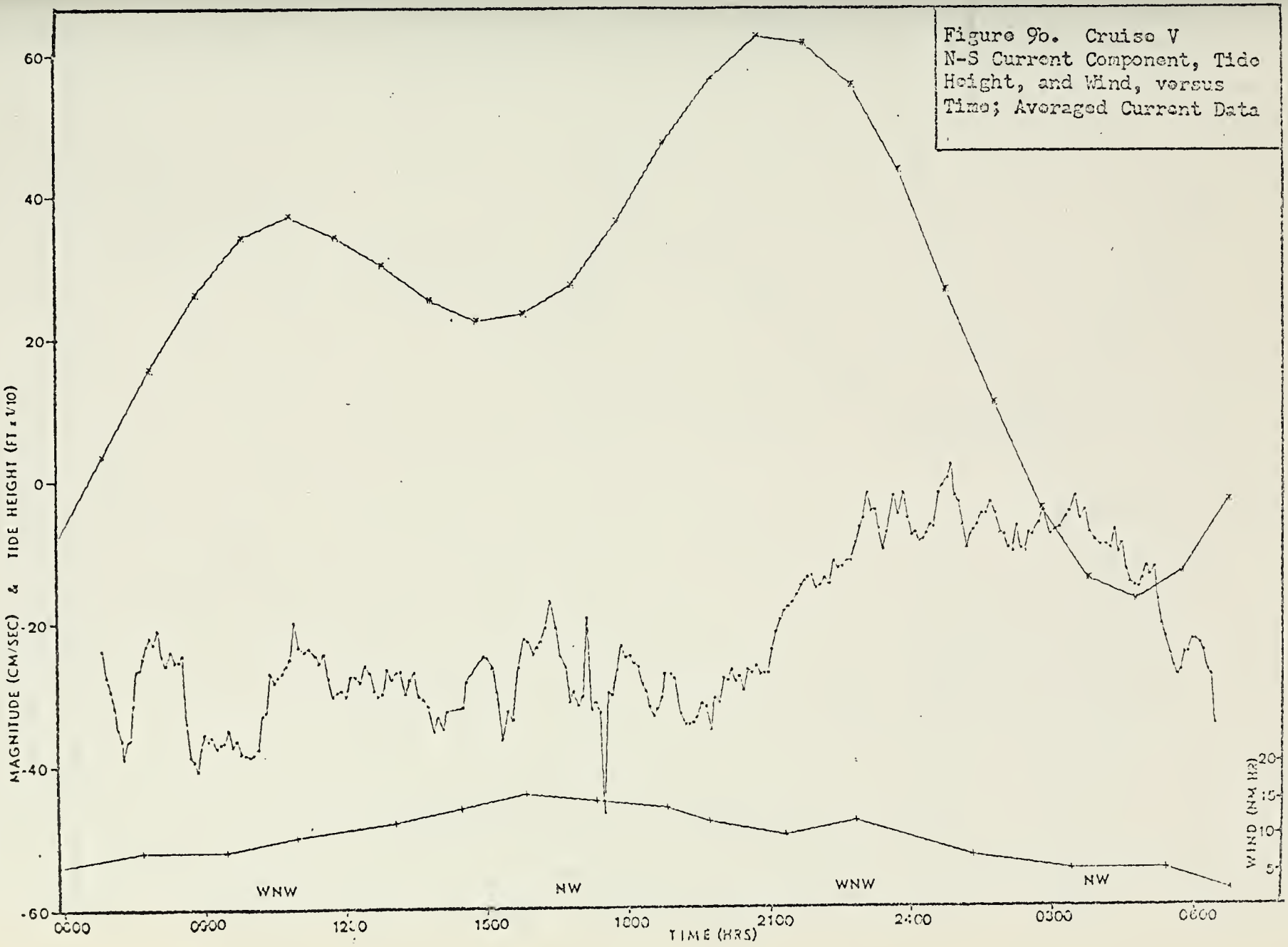


Figure 9b. Cruise V
N-S Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

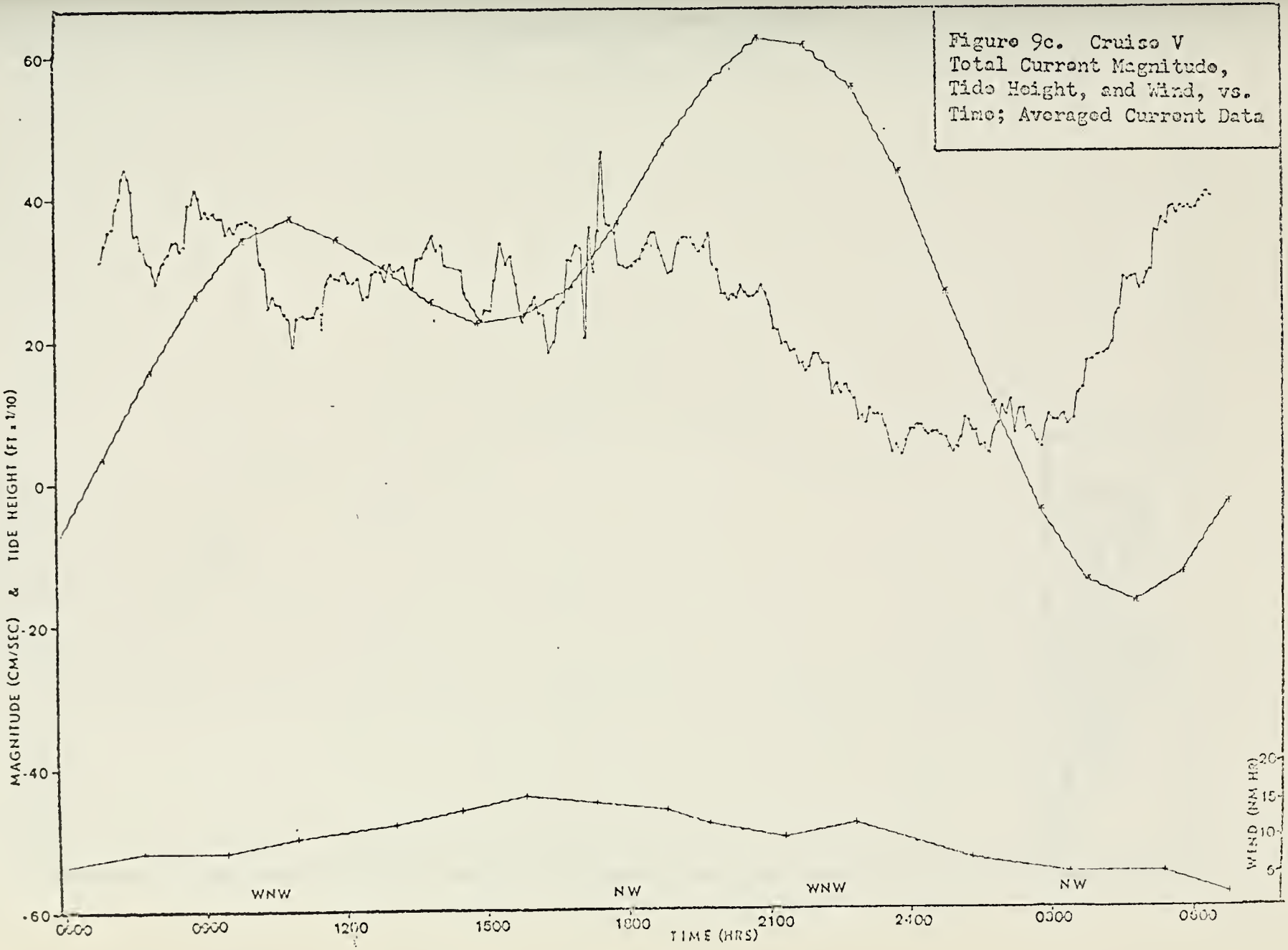


Figure 9c. Cruise V
Total Current Magnitude,
Tide Height, and Wind, vs.
Time; Averaged Current Data

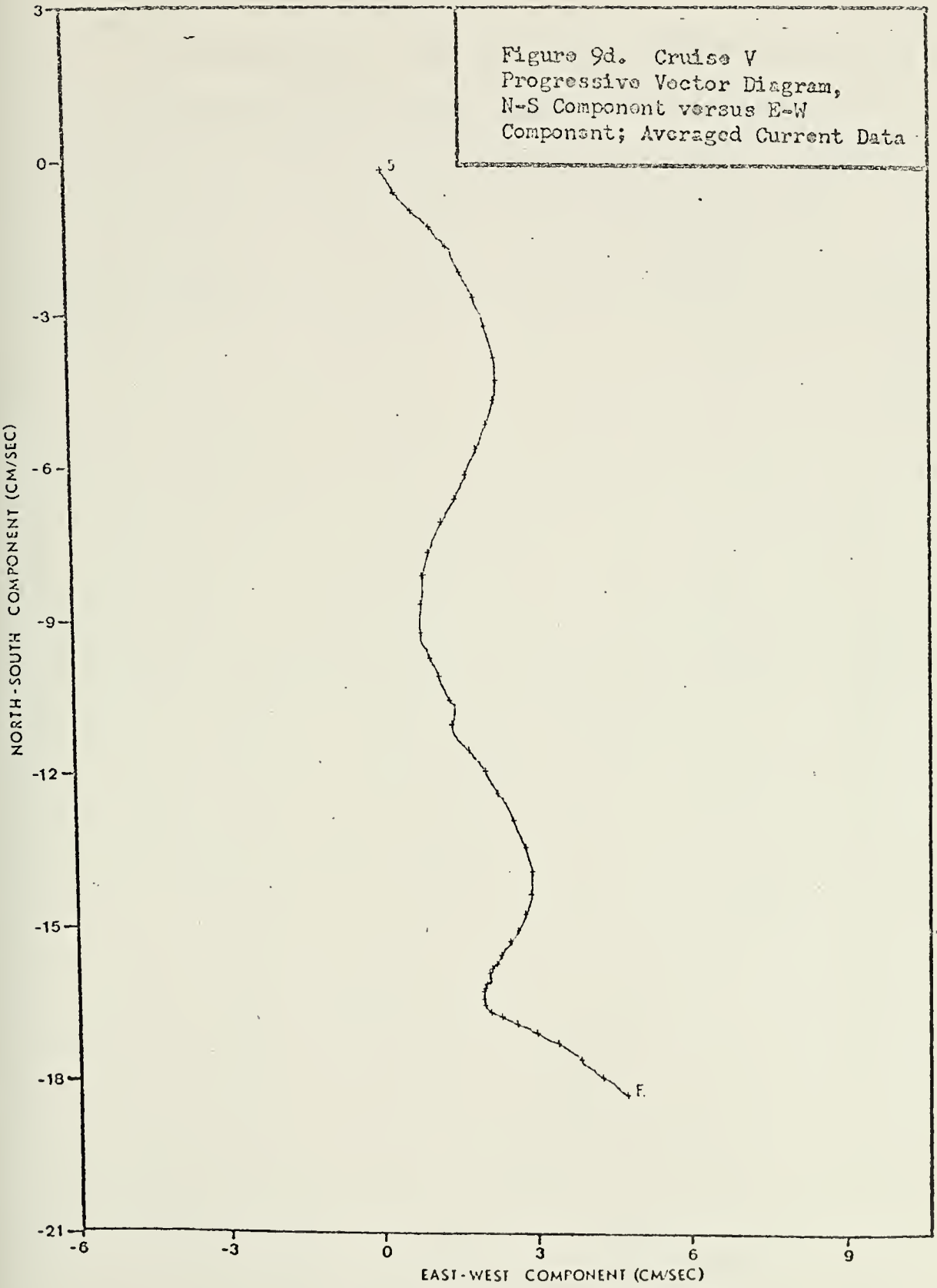
Figure 9d. Cruise V
Progressive Vector Diagram,
N-S Component versus E-W
Component; Averaged Current Data
S
F
3
0
-3
-6
-9
-12
-15
-18
-21
-6
-3
0
3
6
9
NORTH-SOUTH COMPONENT (CM/SEC)
EAST-WEST COMPONENT (CM/SEC)

6. Cruise VI

Period: 20 - 21 July 1972

Sea and Weather: Winds were predominantly southerly with velocities below 10 knots. There was a mixed swell, but it was mostly from the west and southwest with a southerly sea of 1 to 2 feet. It was overcast during much of this cruise.

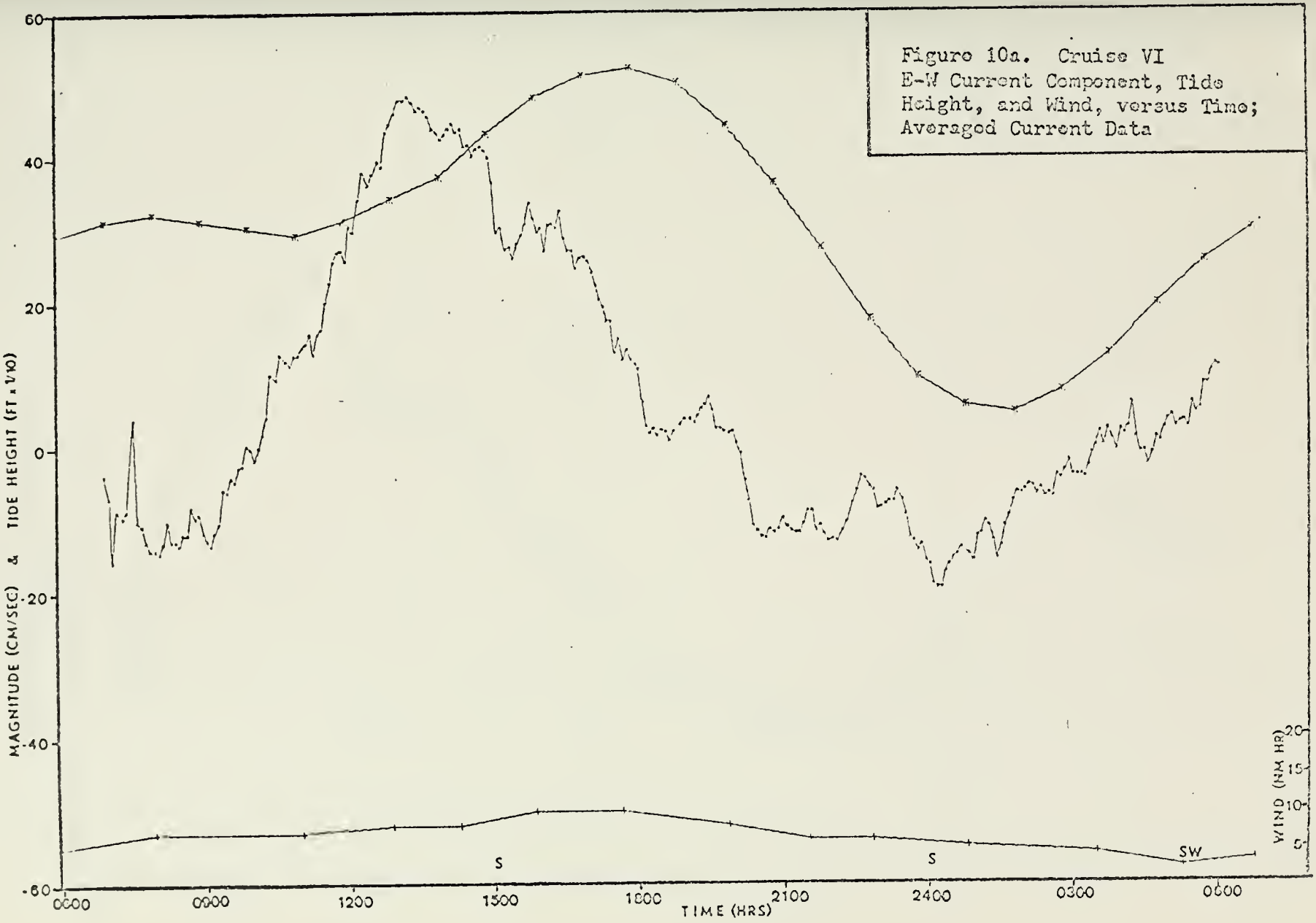


Figure 10a. Cruise VI
E-W Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

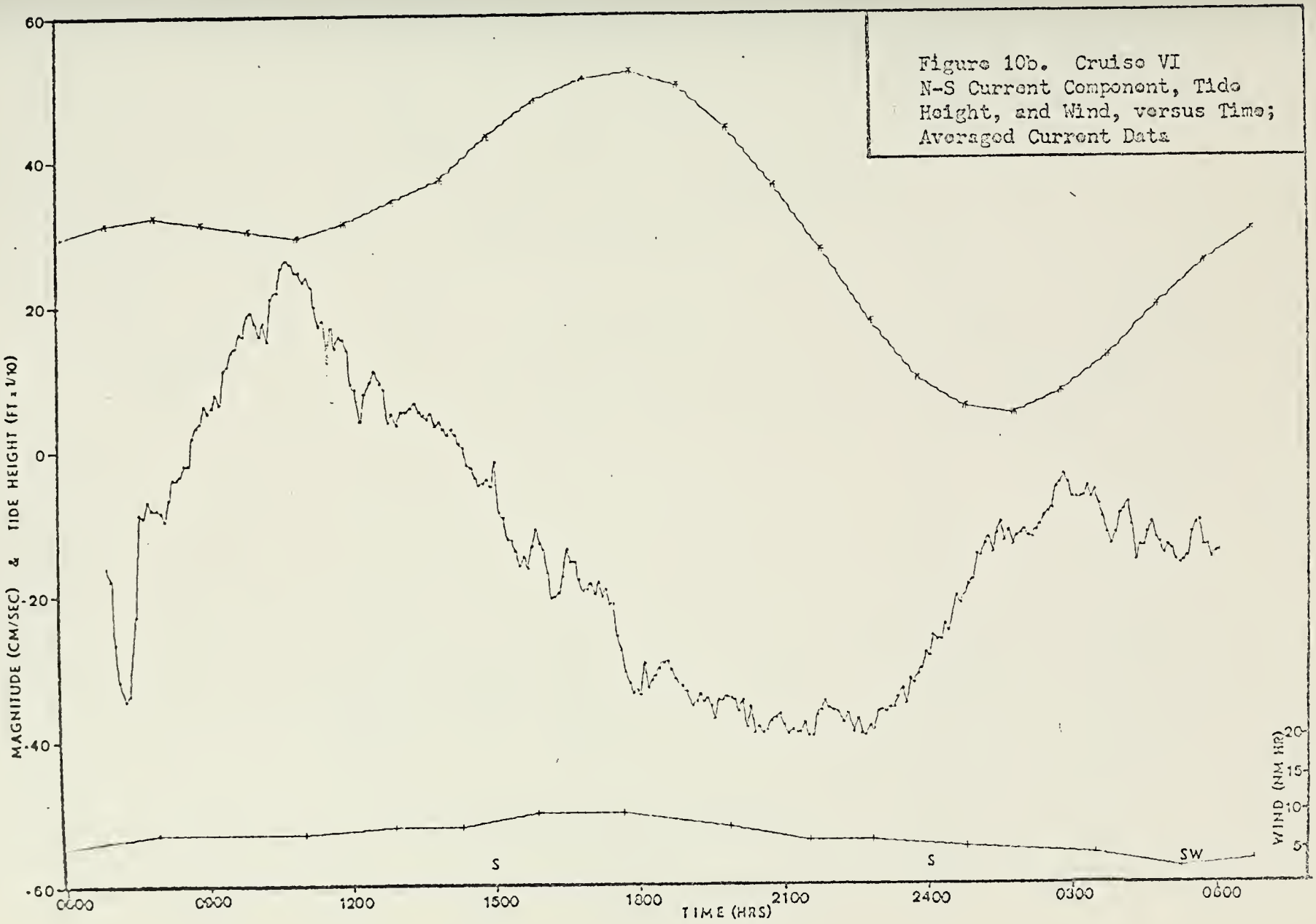


Figure 10b. Cruise VI
N-S Current Component, Tide Height, and Wind, versus Time; Averaged Current Data

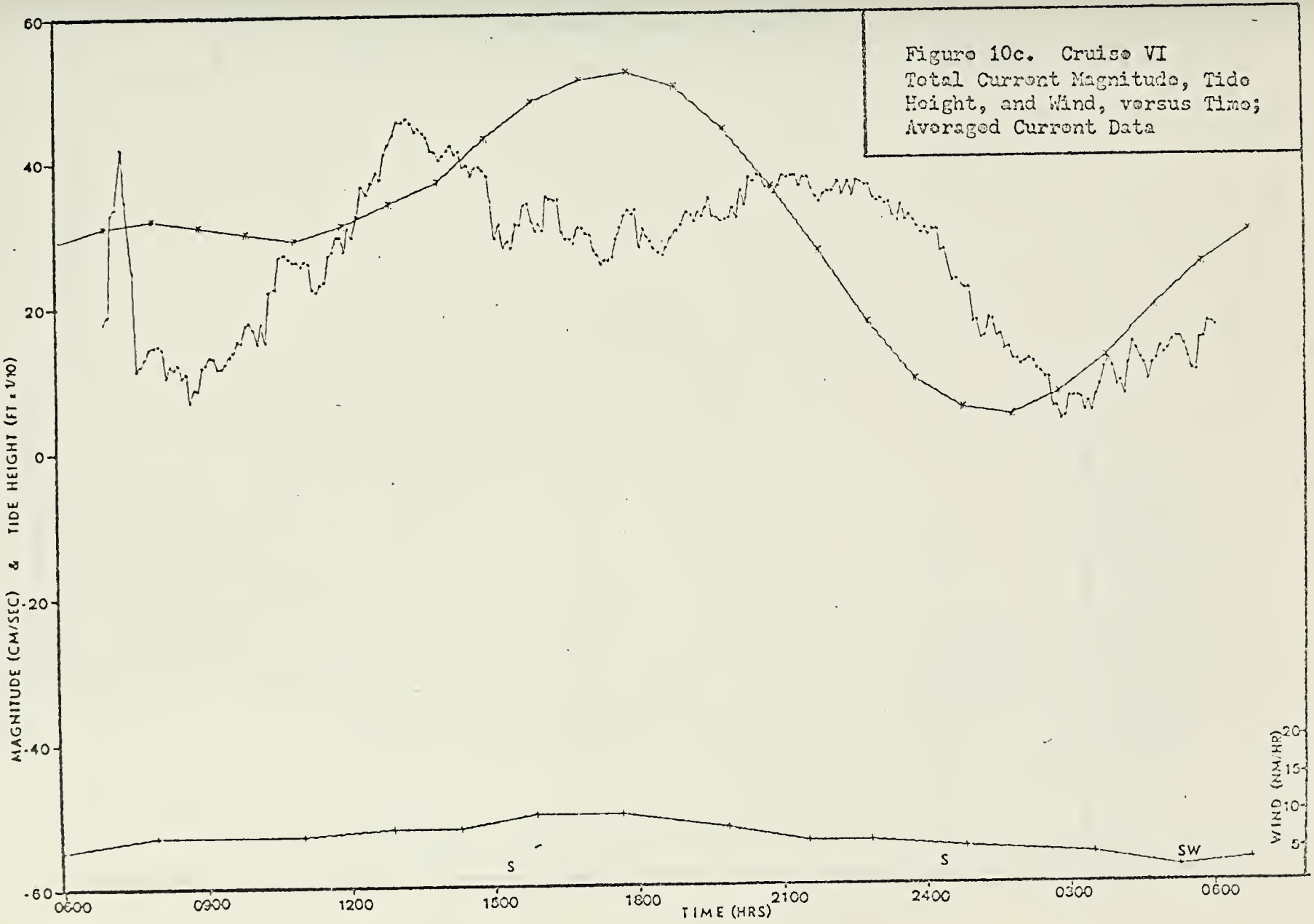


Figure 10c. Cruise VI
Total Current Magnitude, Tide Height, and Wind, versus Time; Averaged Current Data

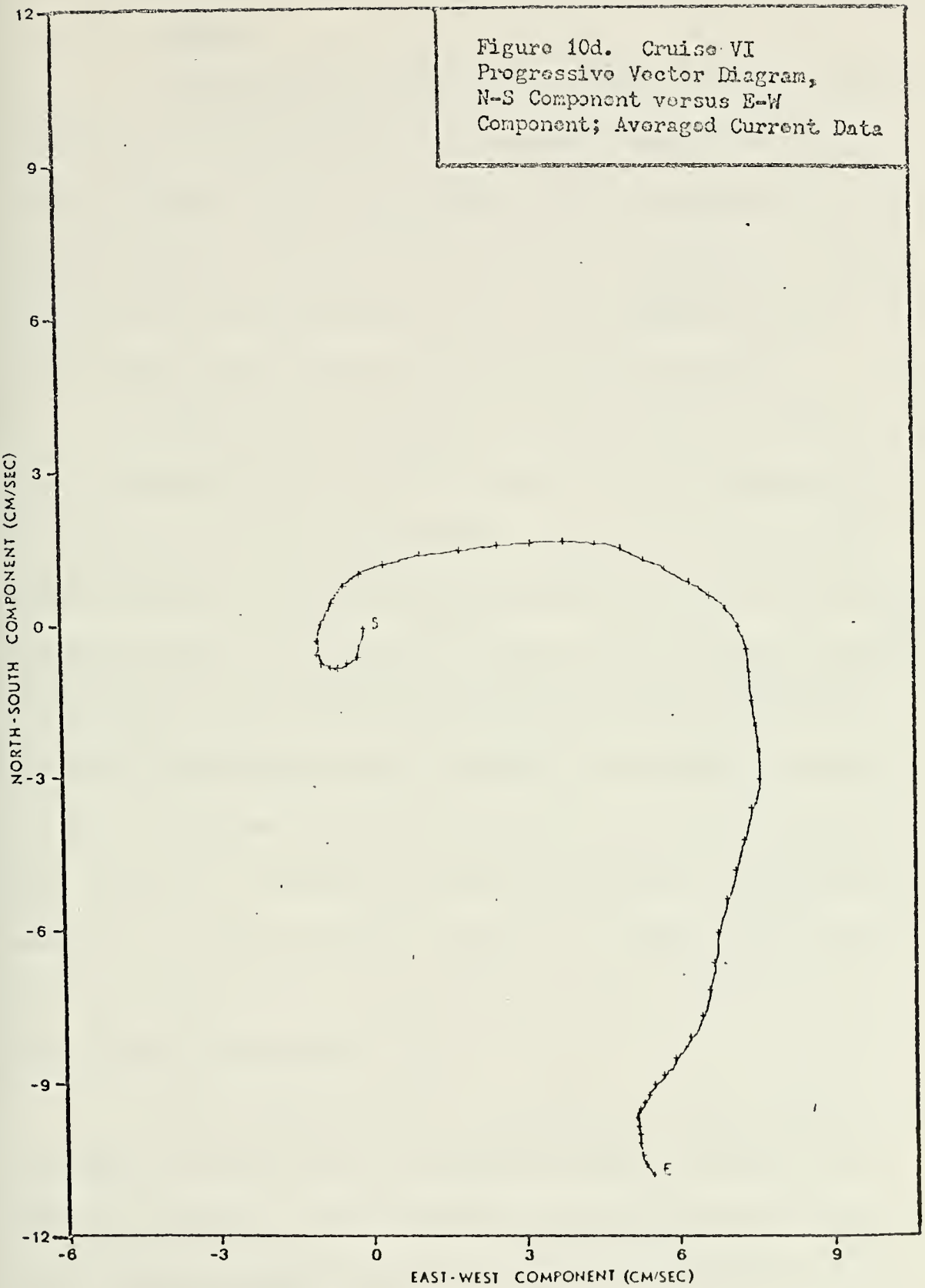


Figure 10d. Cruise VI
Progressive Vector Diagram,
N-S Component versus E-W
Component; Averaged Current Data

## C. DISCUSSION

### 1. General

This section deals with the mean currents and their relation to the wind and seasonal effects. The currents in Monterey Bay are weak and variable and have as yet defied accurate description. The current data gathered during this research and its relationship to oceanic currents, the winds, and seasonal effects may, together with other investigations, lead to a viable picture of the bay's circulation.

The averages of the mean components for the six cruises are 11.6 cm/sec to the south and 3.6 cm/sec to the east. These yield a resultant of 12.1 cm/sec toward 163°T. No data are available which may be compared accurately to the present results. However, for purposes of rough comparison, Table I gives the mean for each cruise and currents derived from dynamic heights by Moomy (results yet to be published). The points between which Moomy's transports are computed are shown in Figure 4. The mean of Moomy's data is 15 cm/sec, and of the present data, 12 cm/sec. However, the standard deviations are relatively large and the close agreement probably is fortuitous. However, the generally southerly trend of all the mean directions of the time series data is in good agreement with Moomy's data.

The "upwelling period," during which this current data was collected, has been described by Skogsberg (1936) as extending from February to September, and as having the same prevailing northwesterly winds as were experienced during this research. Lammers (1971) noted

TABLE 1

COMPARISON OF RECENT OCEAN CURRENT MEASUREMENTS

| HOWTON'S DATA<br>MEAN SURFACE CURRENTS FROM 24-HOUR TIME SERIES OF GEK MEASUREMENTS<br>(AVERAGE OF 6 MEANS:12.1/163°T) | | | MOOMY'S DATA<br>TRANSPORT DERIVED FROM DYNAMIC HEIGHTS | | |
|---|---|---|---|---|---|
| DATE | STATION | VEL/DIRC CM/SEC/°T | DATE | STATION | VEL/DIRC CM/SEC/°T |
| | | | 9 May | 3 & 5 | 21 / SE |
| | Data | | | 3 & 4 | 26 / SE |
| 10/11 May | Point | 7.2 / 164 | | 4 & 5 | 3 / NE |
| | | | | 2 & 4 | 8 / S |
| | (Near | | | 2 & 3 | 27 / S |
| | | | 16 May | 2 & 3 | 13 / N |
| 30/31 May | Station #S) | 17.1 / 175 | 17 May | 2 & 3 | 2 / S |
| 19/20 June | Data | 4.1 / 198 | 2 June | 2 & 3 | 11 / S |
| 22/23 June | Point | 11.3 / 135 | | | |
| 10/11 July | | 21.9 / 154 | 6 July | 2 & 3 | 22 / S |
| | Data | | | | |
| | Point | | 19 July | 2 & 3 | 7 / S |
| 20/21 July | | 11.9 / 158 | | | |
| | | | 25 July | 2 & 3 | 14 / S |

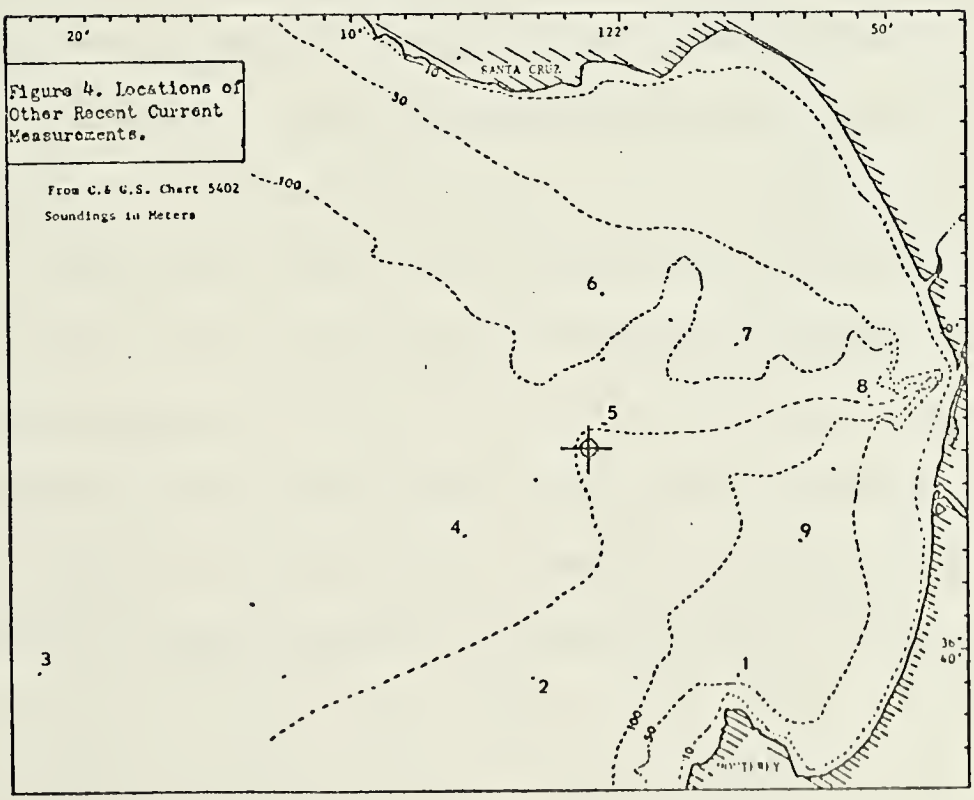


Figure 4. Locations of Other Recent Current Measurements.

From C.& G.S. Chart 5402

Soundings in Meters

that the southern flow of the California Current exists at the seaward edge of Monterey Bay from mid-February to November, while the northerly Davidson Current persists during the balance of the year. Lammers also observed that during the upwelling period the mean velocity of the California Current in this region is from 1.0 to 6.7 nm/day with a mean of 5 nm/day. This generally agrees in both direction and speed with the average of the mean currents from each cruise (5.9 nm/day).

During this set of cruises the wind blew fairly steadily from the west northwest with the exception of Cruise VI, when the wind was from the south and southwest at ten knots or less. If the general southerly flow is due to the prevailing wind, this cruise would be expected to show northerly flows. However, during Cruise VI the mean current maintained its mean southerly flow with only slightly more than the usual easterly component. In checking the progressive vector diagram for Cruise VI it was seen that almost due easterly current flow occurred during the daylight hours when the southerly wind was at its peak. A further study of weather charts for the period showed that the south wind was only a local phenomenon and that west northwest winds prevailed along the coast to the north. The local south wind did have some temporary effect on the surface currents, but the California Current maintained by the prevailing northwest winds along the coast persisted in its steady southerly flow across the mouth of the bay.

2. Variability

By inspection of the unaveraged Total Current Magnitude Graphs (Appendix C) it can be seen that the range of variability over 24 hours is from 2 cm/sec to around 40 cm/sec. The Cruise V Total Current Magnitude graph (Figure 15c) is a good example of this variation and also shows two unusually high magnitudes of over 50 cm/sec. The spacings of the crosses on the Progressive Vector Diagram also give an indication of this current variability (each cross represents five current vectors, or approximately 30 minutes of time) as well as the changeability of the current direction. The Cruise I Progressive Vector Diagram (Figure 5d) shows the clockwise rotation (which may vary through more than 180 degrees) that is typical of all cruises except Cruise V. This directional oscillation is superimposed on a moderate mean southerly flow.

In order to produce numerical estimates of the cyclic components of the currents and to determine their origins, the data was subjected to a fourier analysis. It was recognized that with so short a series (24.8 hours) the diurnal component would not be separated from the inertial component (20 hours at this latitude), and that if there were a substantial amount of noise it would have its usual effect in reducing the reliability of the coefficients. The N-S and E-W components separately were prepared by filling gaps, extrapolating to 24.8 hours total length, and by subtracting the mean. Fourier coefficients, magnitudes, and phase angles were then computed, using the Subroutine

FORIT from the IBM Scientific Subroutines Package (included in Appendix A). This program expresses the coefficients $A_m$ and $B_m$ as those in the equation

$$f(t) = A_o + \sum A_m \cos m\ \omega_o t + \sum B_m \sin m\ \omega_o t \qquad (1)$$

where f(t) represents the time series being analyzed, m is the integer specifying the particular harmonic being calculated and $\omega_o$ is the fundamental angular frequency, which is related to the time duration of the series, T, by

$$\omega_o = \frac{2\pi}{T} \qquad (2)$$

The power present in the mth component is then

$$P_m = 1/2(A_m^2 + B_m^2) \qquad (3)$$

and the magnitude of current speed in that component is

$$C_m = (A_m^2 + B_m^2)^{1/2} \qquad (4)$$

Equivalently, Equation (1) may be expressed as

$$f(t) = C_m \cos(m\ \omega_o t - \alpha_m) \qquad (5)$$

where

$$A_o = 0 \text{ and } \alpha_m = \sin^{-1}\frac{Bm}{C_m} \qquad (6)$$

Here $\alpha_m$ is the phase angle, the number of degrees after the start of each series at which component maximum occurs.

The mean velocity and the phase differences between the diurnal component and the transit of the sun, and the semi-diurnal component

and the transit of the moon are contained in Table II, along with the results of the fourier analysis. The total power present in all the calculable frequencies is also tabulated in this table to facilitate a comparison of this value with the amount of power present in the diurnal and semi-diurnal components. The conclusions to be drawn from this table are the following:

(i) The amplitudes of the diurnal and semi-diurnal components are comparable with the mean velocity.

(ii) The power in the diurnal plus semi-diurnal components is about three-fourths of the total variable power.

(iii) Diurnal components are not consistently more important than the semi-diurnal and vice-versa.

(iv) The variable effects are generally larger in the E-W components than in the N-S components, while for the mean velocities the reverse is true.

(v) The diurnal and semi-diurnal terms in both the N-S and E-W portions of the current have a fairly consistent phase relationship with the meridional transit of the sun and moon respectively.

The phase stability of the fourier components may be seen by comparing the phase angles relative to lunar and solar transit with the respective means.

The variations from the mean of the semi-diurnal does not exceed $\pm$ 2.5 hours in either the E-W or the N-S component except for

TABLE II. FOURIER ANALYSIS RESULTS

| Cruise | | Mean Vel. (cm/sec) | Period (Hours) | A | B | Power $P_m$ ($Vel^2$/CPH) | Total Power $P_T$ | Magnitude (cm/sec) $C_m$ | Phase Angle (degrees) m | Phase Diff. (Hours) Re Sun Transit | Phase Diff. (Hours) Re Moon Transit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EAST-WEST COMPONENT | I | 1.7 | 24.8 | 14 | -14 | 210 | 297 | 20.5 | -43 | -3.3 | |
| | | | 12.4 | -5 | 4 | 23 | | 6.8 | 36 | | +2.6 |
| | II | 2.0 | 24.8 | 6 | 1 | 22 | 154 | 6.6 | 5 | -4.7 | |
| | | | 12.4 | 12 | -5 | 91 | | 13.5 | -21 | | -0.1 |
| | III | -1.2 | 24.8 | 3 | 4 | 16 | 138 | 5.6 | 51 | -2.3 | |
| | | | 12.4 | 10 | 7 | 76 | | 12.3 | 33 | | -3.7 |
| | IV | 8.0 | 24.8 | 15 | 18 | 288 | 325 | 24.0 | 50 | -2.7 | |
| | | | 12.4 | 1 | -1 | 1 | | 1.7 | -37 | | +3.8 |
| | V | 5.5 | 24.8 | 9 | -1 | 39 | 203 | 8.8 | -8 | -5.9 | |
| | | | 12.4 | 14 | -4 | 108 | | 14.7 | -15 | | +1.8 |
| | VI | 5.5 | 24.8 | -7 | 18 | 193 | 351 | 19.6 | 69 | +2.1 | |
| | | | 12.4 | -4 | -13 | 99 | | 14.1 | -72 | | +3.4 |
| AVERAGE: | | +3.6 | | | | 194 | | | | -2.8 | +1.3 |
| NORTH-SOUTH COMPONENT | I | -6.9 | 24.8 | -11 | -7 | 94 | 201 | 13.7 | -30 | -10.3 | |
| | | | 12.4 | 7 | -2 | 26 | | 7.2 | -16 | | -2.6 |
| | II | -17.0 | 24.8 | 7 | -11 | 91 | 278 | 13.5 | -55 | -9.0 | |
| | | | 12.4 | -11 | -1 | 60 | | 10.9 | -4 | | -5.5 |
| | III | -3.9 | 24.8 | -4 | 2 | 9 | 68 | 4.2 | 28 | -17.8 | |
| | | | 12.4 | 3 | -7 | 28 | | 7.5 | -62 | | +5.5 |
| | IV | -8.0 | 24.8 | 3 | -3 | 10 | 152 | 4.5 | -45 | -9.3 | |
| | | | 12.4 | -10 | 6 | 81 | | 12.7 | 31 | | -2.2 |
| | V | -19.6 | 24.8 | 1 | -12 | 71 | 134 | 11.9 | -84 | -11.4 | |
| | | | 12.4 | -6 | -2 | 22 | | 6.6 | -17 | | -3.3 |
| | VI | -11.0 | 24.8 | 11 | 16 | 206 | 317 | 20.3 | 54 | -1.9 | |
| | | | 12.4 | -10 | -3 | 63 | | 11.2 | -14 | | +1.2 |
| AVERAGE: | | -11.6 | | | | 127 | | | | -9.9 | -1.1 |

Cruise III in the E-W and Cruises II and III in the N-S. Similarly, the variation from the mean of the diurnal phase does not exceed $\pm$ 1.9 hours except on Cruises V and VI in the E-W and III and VI in the N-S. Only four out of the 24 variations from the mean exceed one-third of the associated period. Since we are dealing with a time series which is both non-stationary and short, such agreement may be regarded as good. However, the fact that there is not a constant relation between the amplitudes of these two components, and the fact that the phase angles occasionally vary widely from the mean leads to either of two inferences: (a) the currents are driven indirectly by the tides and are considerably modified by some unknown oceanic processes, or (b) inertial rotations are important. This makes one unwilling to say that the coupling of the tide and current is direct, but does indicate that a relationship exists.

## VII. CONCLUSIONS

Currents in Monterey Bay are quite variable in both velocity and direction. Therefore, one cannot describe the mean flow by means of a short-term measurement.

All six cruises yielded mean southerly currents. The average of these means is a current directed 163°T at a speed of 12.1 cm/sec (5.9 nm/day). This result supports Lammers' analysis that the California Current sweeps close to the mouth of Monterey Bay (and the data point) during the upwelling period.

It has been established that there are substantial diurnal and semi-diurnal components which, with a few notable exceptions, have a consistent phase relation with the sun and moon. There obviously must be at least an indirect coupling with the semi-diurnal tide. The diurnal component may be tidal or inertial or merely related to the passage of the sun.

# APPENDIX A

## COMPUTER PROGRAMS

1. Reduction of GEK Data to Current Vectors
2. Graphing of Ocean Current Data versus Winds and Tides
3. Progressive Vector Diagram of Current Vectors
4. Fourier Analysis of Ocean Current Components

```
C TITLE   REDUCTION OF GEK DATA TO CURRENT VECTORS
C
C AUTHOR  H.M.HOWTON
C
C DATE    7 JULY 1972
C
C PURPOSE TO REDUCE ROUGH GEK DATA TO CURRENT COMPONENTS AND VECTORS. GEK DATA
C         IN THE FORM OF DIRECTIONS,VELOCITIES, AND TIME ARE REDUCED TO NORTH
C         AND EAST COMPONENTS AS WELL AS MAGNITUDES AND DIRECTIONS TO DESCRIBE
C         AN OCEAN CURRENT FIELD OVER A PERIOD OF TIME(EG,24 HOUR DATA PERIODS).
C         CORRESPONDING TIMES ARE PRINTED WITH EACH CURRENT VECTOR.
C
C CAUTION PROGRAM IS WRITTEN FOR SHIPSCOURSE TO BE ONLY TRUE CARDINAL DIRECTIONS
C
      DIMENSION V(300),XV(300),YV(300),MT(300),D(300),AMAG(300),
     1DIR(300),VV(300),R(200),AMT(200),BMAG(300),NT(300),MNT(300)
C   DEFINE, N= NUMBER OF DATA POINTS,DD= INITIAL SHIP'S COURSE,RIGHT= LEFT
C   OR RIGHT ROTATION,ISTOP=PROGRAM STOP SIGNAL, V= ARRAY OF VELOCITIES FOR
C   EACH LEG OF SQUARES, MT= CORRESPONDING TIMES FOR EACH LEG,IPRT=PUNCH SIGNAL
      NAMELIST/GEKK/ N,DD,RIGHT,ISTOP,V,MT,IPRT
      IPRT=0
      ISTOP=0
C   READ IN ROUGH DATA FROM DATA CARDS.
 20   READ(5,GEKK)
      IF(ISTOP.GT.0) GO TO 999
 21   PI2=3.14159/2.0
      RAD=3.14159/180.0
C   CHANGE DIRECTION TO RADIANS.
      DD=DD*RAD
      II=N-2
      DO 32 K=1,II
C   DIVIDE BY 100 AND TRUNCATE TO SEPERATE HOURS FROM MINUTES. NT IS THE
C   HOURS PART, MNT IS THE MINUTES PART.
      NT(K)=MT(K+1)/100.0
      MNT(K)=MT(K+1)-(100.0*NT(K))
      IF(MNT(K).GE.57) GO TO 61
C   ADD 3 MINUTES TO THE TIME TO GET THE MIDDLE OF THE INTERVAL. THE
C   NEXT STEP PROTECTS AGAINST OVERSTEPPING THE NEXT HOUR IN THIS PROCESS
C   AND GETTING MINUTES GREATER THAN 60.
      MT(K)=MT(K+1)+3
      GO TO 32
 61   MT(K)=MT(K+1)-MNT(K)+100.0+(-57.0+MNT(K))
 32   CONTINUE
      NN=N-1
      DO 25 J=2,NN
      XJ=J-1
C   DIRECTION IS 90 DEG. TO RIGHT OF STARTING DIRECTION,DD,AND INCREMENTING BY
```

```
C    90 DEGREES EACH STEP(RIGHT=+1.) FOR ROTATION TO LEFT LET'RIGHT=-1.'
       CORD=XJ*PI2*RIGHT
       D(J)=DD+PI2+CORD
C    ZERO DERIVED FROM TWO OPPOSITE LEGS.
 525   ZERO=(V(J-1)+V(J+1))/2.0
C    TWO VALUES ARE CALCULATED FOR EACH SIDE AFTER SIDE #1. THESE VV(J) AND
C    VV(J-1) VALUES ARE LATER CONVERTED TO E-W AND N-S COMPONENTS (ALTERNATELY).
       VV(J)=V(J)-ZERO
       I=(J-1)
       VV(I)=V(J-1)-ZERO
       K=(J-1)
       FAC=-1.0
       D(J)=D(J)/RAD
       D(J)=AMOD(D(J),360.)
C    TO CORRECT DIRECTIONS IF ROTATION IS TO THE LEFT(RIGHT=-1).
       IF(D(J).LT.0.2) GO TO 519
       GO TO 526
 519   D(J)=ABS(D(J))
       IF(D(J).LT.00.2) GO TO 530
       IF(D(J).LT.090.2) GO TO 531
       IF(D(J).LT.180.2) GO TO 532
       IF(D(J).LT.270.2) GO TO 533
       IF(D(J).LT.360.2) GO TO 530
 531   D(J)=270.0
       GO TO 526
 532   D(J)=180.0
       GO TO 526
 533   D(J)=090.0
       GO TO 526
 530   D(J)=360.0
C    DETERMINE SIGN(I.E. DIRECTION) OF EACH E-W OR N-S COMPONENT DERIVED FROM
C    VV(J) VALUES.
 526   IF(D(J).LT.090.2) GO TO 121
       IF(D(J).LT.180.2) GO TO 122
       IF(D(J).LT.270.2) GO TO 123
       IF(D(J).LT.360.2) GO TO 124
       IF(D(J).LT.0.2) GO TO 124
       GO TO 26
 121   XV(K)=VV(J)
       GO TO 26
 122   YV(K)=VV(J)*FAC
       GO TO 26
 123   XV(K)=VV(J)*FAC
       GO TO 26
 124   YV(K)=VV(J)
C    DETERMINE SIGN(I.E. DIRECTION) OF EACH E-W OR N-S COMPONENT DERIVED FROM
C    VV(J-1) VALUES
 26    IF(D(J-1).LT.90.2) GO TO 41
```

```
      IF(D(J-1).LT.180.2) GO TO 42
      IF(D(J-1).LT.270.2) GO TO 43
      IF(D(J-1).LT.360.2) GO TO 44
      IF(D(J-1).LT.0.2) GO TO 44
 41   XV(K)=VV(I)
      GO TO 25
 42   YV(K)=VV(I)*FAC
      GO TO 25
 43   XV(K)=VV(I)*FAC
      GO TO 25
 44   YV(K)=VV(I)
 25   CONTINUE
 185  DO 170 K=1,NN
C    CALCULATE THE MAGNITUDE OF THE CURRENT.
      AMAG(K)=SQRT(XV(K)*XV(K)+YV(K)*YV(K))
      IF(XV(K)/AMAG(K).GT.1.0) GO TO 350
      GO TO 36
 350  WRITE(6,355) AMAG
 355  FORMAT(' ',30X,'CHECK VALUES',F9.2)
C    COMPUTE THE CURRENT DIRECTION.
 36   DIR(K)=ARSIN(XV(K)/AMAG(K))
C    MULTIPLY BY THE COMPENSATION FACTOR FOR LOCAL AFFECTS OF THE EARTH'S
C    MAGNETIC FIELD.
      BMAG(K)=1.04*AMAG(K)*.91
C    ORIENT DIRECTION INTO PROPER QUADRANT.
      IF(XV(K).GT.0.0) GO TO 150
      IF(YV(K).GT.0.0) GO TO 160
      DIR(K)=2*PI2-DIR(K)
      GO TO 170
 150  IF(YV(K).GT.0.0) GO TO 170
      DIR(K)=2*PI2-DIR(K)
      GO TO 170
 160  DIR(K)=4*PI2+DIR(K)
 170  DIR(K)=(180.0/3.14159)*DIR(K)
 190  IF(IPRT.EQ.0) GO TO 20
C    PUNCH SMOOTH CURRENT DATA OUT ON DATA CARDS.
 200  DO 205 K=2,NN
      NUM=K*10
      WRITE(7,210)XV(K),YV(K),MT(K),BMAG(K),DIR(K),NUM
 210  FORMAT(2X,F9.2,3X,F9.2,3X,I4,3X,F9.2,5X,F9.2,16X,I8)
 205  CONTINUE
      GO TO 20
 999  STOP
      END
```

```
C TITLE    GRAPHING OF OCEAN CURRENT DATA VERSUS WINDS AND TIDES
C
C AUTHOR   H.M. HOWTON
C
C DATE     15 SEPTEMBER 1972
C
C PURPOSE  TO  PRESENT IN GRAPHICAL FORM THE CURRENT VELOCITY COMPONENTS
C          (E-W,N-S,AND CURRENT MAGNITUDE) ON THE SAME PLOT WITH THE
C          GRAPHS OF WIND MAGNITUDE AND TIDAL HEIGHT.
C
C
      DIMENSION XV(300),YV(300),MT(300),BMAG(300),DIR(300),PST(300),MIN(
     1300),M(300),GTIDE(50),TIME(50),TIDE(50),WIND(50),TIMY(50),APST(300
     2),ABMAG(300),AYV(300),AXV(300)
C     WIND AND TIDE DATA IS READ VIA NAMELIST FORMAT FROM DATA CARDS.
      NAMELIST/WINDY/ NB,WIND,TIMY
      NAMELIST/TIDHT/NM,TIME,TIDE
      ISTOP=0
      IF(ISTOP.GT.0) GO TO 999
      READ(5,TIDHT)
      READ (5,WINDY)
C     SET IN NUMBER OF DATA POINTS.
      N=260
C     READ SMOOTH CURRENT DATA FROM DATA CARDS.
      DO 15 K=1,N
   15 READ(5,325)XV(K),YV(K),MT(K),BMAG(K),DIR(K)
  325 FORMAT(2X,F9.2,3X,F9.2,3X,I4,3X,F9.2,5X,F9.2)
C     CONVERT TIME FROM NORMAL 24 HOUR DAY TO CONTINUOUS TIME BEGINNING
C     AT CRUISE START.TIME IS ALSO CHANGED TO DECIMAL FORMAT.
C     CHANGE TIME FROM DAYLIGHT SAVINGS TIME TO STANDARD(PST) TIME.
      DO 387 K=1,N
      M(K)=MT(K)/100.0
      MIN(K)=MT(K)-(100.0*M(K))
      PST(K)=(MIN(K)/60.0)+M(K)-1.0
      IF(PST(K).LT.PST(1).AND.PST(K).GT.0.0) PST(K)=PST(K)+24.00
      IF(PST(K).LT.0.0) PST(K)=23.0+(1+PST(K))
  387 CONTINUE
      L=N-2
C     AVERAGE ALTERNATE DATA POINTS TO SMOOTH DATA. THIS PROGRAM WAS
C     ALSO RUN WITH UNAVERAGED DATA.
      DO 330 K=1,L
      APST(K)=(PST(K)+PST(K+2))/2.0
      ABMAG(K)=(BMAG(K)+BMAG(K+2))/2.0
      AYV(K)=(YV(K)+YV(K+2))/2.0
      AXV(K)=(XV(K)+XV(K+2))/2.0
  330 CONTINUE
C     SET IN THE START TIME OF THE CRUISE.
      ATIM=6.00
```

```
C       SET UP SCALING FACTORS.
        DO 14 K=1,N
        APST(K)=(APST(K)-ATIM)/3.0
        AYV(K)=(AYV(K)+60.0)/20.0
 14     CONTINUE
C       CALL THE PLOTTING PACKAGE TO GRAPH THE CURRENT COMPONENTS,WIND
C       MAGNITUDES,AND THE TIDE HEIGHTS.
        CALL PLOTS
        REAL XTITLE/'TIME'/
        REAL YTITLE/'COMP'/
        CALL AXIS(0.0,0.0,XTITLE,-04,9.,0.0,ATIM,3.0)
        CALL AXIS(0.0,0.0,YTITLE,+04,6.0,090.0,-60.0,20.)
        REAL X(3)/0.0,9.0,9.0/
        REAL Y(3)/6.0,6.0,0.0/
        CALL LINE(X,Y,3,1,1)
        CALL LINE(APST,AYV,L,1,7)
        DO 16 J=1,NM
        GTIDE(J)=TIDE(J)+2.1
        GTIDE(J)=(GTIDE(J)+6.0)/2.0
        TIME(J)=(TIME(J)-ATIM)/3.0
 16     CONTINUE
        CALL LINE(TIME,GTIDE,NM,1,5)
        DO 18 I=1,NB
        TIMY(I)=(TIMY(I)-ATIM)/3.0
        WIND(I)=WIND(I)/20.0
 18     CONTINUE
        CALL LINE(TIMY,WIND,NB,1,2)
        CALL SYMBOL(0.0,7.2,0.14,'HOWTON',0.0,6)
        CALL SYMBOL(0.0,6.5,0.14,'          CRUISE #5 N-S COMPONENT VS TID
      1E AND WIND -AVERAGED DATA',0.0,65)
        CALL PLOT(0.0,12.0,-3)
        CALL PLOTE
 999    STOP
        END
```

```
C TITLE     PROGRESSIVE VECTOR DIAGRAM OF CURRENT VECTORS
CC
C AUTHOR    H.M. HOWTON
CC
C DATE      26 OCTOBER 1972
CC
C PURPOSE.  TO PRESENT SMOOTH CURRENT DATA AS A SERIES OF PROGRESSIVE
C           VECTORS. CURRENT VELOCITIES ARE CONVERTED TO DISTANCES BY
C           MULTIPLYING BY THE TIME INCREMENT OVER WHICH THAT PARTICULAR
C           VELOCITY ACTS. THE PLOTTING PACKAGE BY P.C.JOHNSON(1969) IS
C           UTILIZED TO PRODUCE SIX BY EIGHT INCH DIAGRAMS.
CC
C
      DIMENSION XV(300),YV(300),MT(300),BMAG(300),DIR(300),PST(300),MIN(
     1300),M(300),GTIDE(50),TIME(50),TIDE(50),WIND(50),TIMY(50),APST(300
     2),ABMAG(300),AYV(300),AXV(300),VEW(300),VNS(300),SVEW(300),SVNS(30
     30),FIVEW(300),FIVNS(300)
      INTEGER O
C     SET IN THE NUMBER OF DATA POINTS.
      N=275
C     READ SMOOTH CURRENT DATA FROM DATA CARDS
      DO 15 K=1,N
   15 READ(5,325)XV(K),YV(K),MT(K),BMAG(K),DIR(K)
  325 FORMAT(2X,F9.2,3X,F9.2,3X,I4,3X,F9.2,5X,F9.2)
C     CONVERT TIME FROM NORMAL 24 HOUR DAY TO CONTINUOUS TIME BEGINNING
C     AT CRUISE START.TIME IS ALSO CHANGED TO DECIMAL FORMAT.
      DO 387 K=1,N
      M(K)=MT(K)/100.0
      MIN(K)=MT(K)-(100.0*M(K))
      PST(K)=(MIN(K)/60.0)+M(K)-1.0
      IF(PST(K).LT.PST(1).AND.PST(K).GT.0.0) PST(K)=PST(K)+24.00
      IF(PST(K).LT.0.0) PST(K)=23.0+(1+PST(K))
  387 CONTINUE
C     AVERAGE ALTERNATE PAIRS, REMOVES AN ARTIFACT FROM THE DATA.
      L=N-2
      DO 330 K=1,L
      APST(K)=(PST(K)+PST(K+2))/2.0
      ABMAG(K)=(BMAG(K)+BMAG(K+2))/2.0
      AYV(K)=(YV(K)+YV(K+2))/2.0
      AXV(K)=(XV(K)+XV(K+2))/2.0
  330 CONTINUE
      I=K
      LLL=L-1
      DO 397 I=2,LLL
      J=I-1
C     CALCULATE TIME INCREMENT FOR EACH CURRENT VECTOR
      TAME=(APST(I+1)-APST(I-1))/2.0
C     CHANGE EACH CURRENT VECTOR TO A DISTANCE,EG. MULTIPLY BY THE TIME
```

```
C       INCREMENT . CONVERT TO KILOMETERS.
        VEW(J)= AXV(I)*(TAME)*(36.0/1000.0)
        VNS(J)= AYV(I)*(TAME)*(36.0/1000.0)
 397    CONTINUE
        SVEWS=0.0
        SVNSS=0.0
        O=L-2
C       SUM UP EACH INDIVIDUAL DISTANCE AND STORE EACH PROGRESSIVE SUM
C       IN A NEW ARRAY IN PREPARATION FOR PLOTTING.
        DO 407 J=1,O
        SVEWS=SVEWS+VEW(J)
        SVNSS=SVNSS+VNS(J)
        SVEW(J)=SVEWS
        SVNS(J)=SVNSS
 407    CONTINUE
C       SET UP NEW ARRAY TO MARK ONLY EVERY FIFTH DATA POINT ON DIAGRAM.
        KI=1
        DO 374 J=1,O,5
        FIVEW(KI)=SVEW(J)
        FIVNS(KI)=SVNS(J)
        KI=KI+1
 374    CONTINUE
C       PLOT THE PROGRESSIVE VECTOR DIAGRAM USING THE PLOTTING PACKAGE.
        CALL PLOTS
C       SCALE THE DATA FOR PLOTTING
        XMIN=-6.0
        YMIN=-12.0
        DY=3.0
        DX=3.0
        DO 414 J=1,O
        SVEW(J)=(SVEW(J)-XMIN)/DX
        SVNS(J)=(SVNS(J)-YMIN)/DY
 414    CONTINUE
        CALL AXIS(0.0,0.0,'EAST',-04,6.0,0.0,XMIN,DX)
        CALL AXIS(0.0,0.0,'NORTH',+05,8.0,090.0,YMIN,DY)
        REAL XS(3)/0.0,6.0,6.0/
        REAL YS(3)/8.0,8.0,0.0/
        CALL LINE(XS,YS,3,1,1)
        CALL LINE(SVEW,SVNS,O,1,1)
        KN=N/5
        DO 413 KI=1,KN
        FIVEW(KI)=(FIVEW(KI)-XMIN)/DX
        FIVNS(KI)=(FIVNS(KI)-YMIN)/DY
 413    CONTINUE
        CALL LINE(FIVEW,FIVNS,KN,1,-2)
        CALL SYMBOL(0.0,9.0,0.14,'HOWTON',0.0,6)
        CALL SYMBOL(0.8,8.5,0.14,'CRUISE #6 PROGRESSIVE VECTOR DIAGRAM',0.
       10,36)
```

```
      XX=SVEW(1)+.06
      YY=SVNS(1)
      CALL SYMBOL(XX,YY,0.07,'S',0.0,1)
      XXX=SVEW(0)+.06
      YYY=SVNS(0)
      CALL SYMBOL(XXX,YYY,0.07,'E',0.0,1)
      CALL PLOT(0.0,12.0,-3)
      CALL PLOTE
999   STOP
      END
```

```
C TITLE    FOURIER ANALYSIS OF OCEAN CURRENT COMPONENTS
C
C AUTHOR   H.M. HOWTON
C
C DATE     15 NOVEMBER 1972
C
C PURPOSE  TO CALCULATE THE COEFFICIENTS OF THE FOURIER SERIES APPROXIMATION
C          OF THE N-S AND E-W COMPONENTS OF A TIME SERIES OF CURRENT
C          VECTORS. THE DATA SET HAS BEEN EXTRAPOLATED TO COVER APPROXIMATELY
C          24.84 HOURS IN ORDER TO MOST EFFECTIVELY SEE SEMI-DIURNAL PERIODS.
C          SINCE THE SAMPLING INTERVAL WAS NOT CONSTANT IN THE SHORT TERM,
C          THIS VERSION RECOMPUTES THE DATA TO A UNIFORM SIX MINUTE INTERVAL
C          BY INTERPOLATION. USES IBM SCIENTIFIC SUBROUTINE PACKAGE PROGRAM
C          'FORIT' TO COMPUTE FOURIER COFFICIENTS.
C
C
      DIMENSION XV(300),YV(300),BMAG(300),DIR(300),MT(300),A(300),B(300)
     1,F(300),GMAG(300),PHASE(300),XX(300),YY(300),TT(300),PST(300),WM(3
     200),MIN(300)
      N=131
      MM=(2*N)+1
C     READ SMOOTH CURRENT DATA FROM DATA CARDS.
      DO 26 J=1,MM
 26   READ(5,101)XV(J),YV(J),MT(J),BMAG(J),DIR(J)
 101  FORMAT(2X,F9.2,3X,F9.2,3X,I4,3X,F9.2,5X,F9.2)
      COR=0.0
C     CONVERT TIME FROM NORMAL 24 HOUR DAY TO CONTINUOUS TIME BEGINNING
C     AT CRUISE START.TIME IS ALSO CHANGED TO DECIMAL FORMAT.
C     CHANGE TIME FROM DAYLIGHT SAVINGS TIME TO STANDARD(PST) TIME.
      DO 387 J=1,MM
      IF(MT(J).LT.MT(1)) COR=24.0
      MH=MT(J)/100
      XMH=MH
      XMIN=MT(J)-MH*100.0
      XMIN=XMIN/60.0
      PST(J)=XMH+XMIN-1.0+COR
 387  CONTINUE
      NUM=249
      NNUM=(NUM-1)/2
C     SET UP NEW TIME ARRAY WITH REGULAR SIX MINUTE INTERVALS,STARTING
C     SLIGHTLY LATER THAN THE ORIGINAL SERIES.
      TT(1)=PST(1)+.001
      XX(1)=XV(1)
      YY(1)=YV(1)
      DO 35 K=2,NUM
      TT(K)=TT(K-1)+.1
 35   CONTINUE
      K=2
```

```
      J=2
C     TIMES FROM THE NEW ARRAY ARE ADJUSTED TO THE PROPER PLACE IN THE
C     ORIGINAL TIME SEQUENCE.
  133 IF(TT(K).GE.PST(J).AND.TT(K).LT.PST(J+1)) GO TO 135
      J=J+1
      GO TO 133
C     BY INTERPOLATION COMPUTE THE N-S AND E-W COMPONENTS AT EACH
C     REGULAR INTERVAL.
  135 TMTT=(TT(K)-PST(J))/(PST(J+1)-PST(J))
      XX(K)=XV(J)+(TMTT)*(XV(J+1)-XV(J))
      YY(K)=YV(J)+(TMTT)*(YV(J+1)-YV(J))
      K=K+1
      IF(K.GT.NUM) GO TO 138
      GO TO 133
  138 SUM=0.0
C     COMPUTE THE SUM OF EACH SET OF COMPONENTS,PREPARATORY TO EXTRACTING
C     THE MEAN FROM THE DATA.
      DO 221 K=1,NUM
      SUM=SUM+XX(K)
  221 CONTINUE
      XMM=MM
C     CALCULATE THE AVERAGE OF EACH SET OF COMPONENTS.
      AVG=SUM/XMM
      WRITE(6,226) AVG
  226 FORMAT('1',5X,F18.7)
C     REMOVE THE MEAN BEFORE PLOTTING.
      DO 231 K=1,NUM
      XX(K)=XX(K)-AVG
      YY(K)=YY(K)-AVG
  231 CONTINUE
      M=NNUM
C     CALCULATE THE COEFFICIENTS OF THE FOURIER SERIES APPROXIMATION OF
C     N-S AND E-W COMPONENTS TO 'NNUM' TERMS.
      CALL FORIT(XX,NNUM,M,A,B,IER)
      IF(IER.GT.0) GO TO 998
      MMM=M+1
      SUMSQR=0.0
      DO 480 J=1,MMM
      AJH=J-1
      F(J)=AJH/24.84
C     SQR IS THE ENERGY IN A FOURIER COMPONENT IN UNITS OF  (CM/SEC)**2
C     PER TERM OF THE SERIES. SUMSQR MEASURES THE TOTAL VARIANCE.
      SQR=(A(J)*A(J)+B(J)*B(J))/2.0
      SUMSQR=SUMSQR+SQR
      GMAG(J)=SQRT(SQR)
C     PHASE IS COMPUTED FOR THE PRINCIPAL QUADRANTS. CORRECTION TO QUADRANTS
C     TWO AND THREE IS DONE EXTERNAL TO THE PROGRAM.
      PHASE(J)=ARSIN(B(J)/(SQRT(2.0*SQR)))
```

```
      PHASE(J)=PHASE(J)*(180./3.14159)
480   WRITE(6,485) J,AJH,F(J),A(J),B(J),SQR,PHASE(J)
485   FORMAT(' ',I4,5X,F15.6,5X,F15.6,5X,F15.6,5X,F15.6,5X,F15.6,5X,F15.
     16)
998   WRITE(6,369) IER,SUMSQR
369   FORMAT(' ',60X,I6,10X,F15.6)
999   STOP
      END
```

# APPENDIX B

## SAMPLE DATA FROM CRUISE I

CRUISE I

10 - 11 MAY 1972

WIND DATA

| TIME | | WIND SPEED | WIND DIRECTION |
|---|---|---|---|
| 10 May 1972 | 1230 | 8 | NW |
| | 1415 | 11 | WNW |
| | 1600 | 12 | WNW |
| | 1715 | 16 | NW |
| | 1800 | 20 | WNW |
| | 1955 | 14 | NW |
| | 2100 | 10 | NW |
| | 2300 | 8 | NW |
| 11 May 1972 | 2400 | 8 | NW |
| | 0200 | 2 | VARIABLE |
| | 0400 | 4 | VARIABLE |
| | 0800 | 4 | VARIABLE |
| | 0905 | 6 | WNW |
| | 1000 | 7 | WNW |
| | 1100 | 8 | NW |
| | 1200 | 8 | WNW |
| | 1300 | 9 | WNW |

CRUISE I

10 - 11 MAY 1972

TIDE DATA

| TIME | | TIDE HEIGHT | TIME | | TIDE HEIGHT |
|---|---|---|---|---|---|
| 10 May 1972 | 1200 | -0.90 | 11 May 1972 | 2400 | -0.85 |
| | 1300 | -1.30 | | 0100 | -2.00 |
| | 1400 | -1.30 | | 0200 | -2.85 |
| | 1500 | -0.70 | | 0300 | -3.05 |
| | 1600 | +0.30 | | 0400 | -2.65 |
| | 1700 | +1.35 | | 0500 | -1.80 |
| | 1800 | +2.40 | | 0600 | -0.70 |
| | 1900 | +3.15 | | 0700 | +0.40 |
| | 2000 | +3.40 | | 0800 | +1.10 |
| | 2100 | +3.00 | | 0900 | +1.45 |
| | 2200 | +2.00 | | 1000 | +1.25 |
| | 2300 | +0.60 | | 1100 | +0.80 |
| | | | | 1200 | +0.10 |
| | | | | 1300 | -0.50 |

CRUISE #1

10-11 MAY 1972

THE FOLLOWING IS A SAMPLE OF DATA AS PRODUCED BY THE DATA REDUCTION COMPUTER PROGRAM. A COMPLETE SET OF DATA FROM ALL SIX CRUISES MAY BE OBTAINED FROM THE NAVAL POSTGRADUATE SCHOOL ON REQUEST.

| TIME (PDT) | NORTH-SOUTH COMP(CM/SEC) | EAST-WEST COMP(CM/SEC) | MAGNITUDE (CM/SEC) | DIRECTION (DEG.TRUE) |
|---|---|---|---|---|
| 1333 | -22.50 | 6.50 | 22.15 | 163.90 |
| 1340 | -18.50 | 2.50 | 17.67 | 172.30 |
| 1346 | -20.50 | 0.50 | 19.41 | 178.60 |
| 1350 | -22.50 | 2.50 | 21.43 | 173.66 |
| 1358 | -25.50 | -0.50 | 24.14 | 181.12 |
| 1406 | -30.50 | 4.50 | 29.18 | 171.61 |
| 1412 | -26.50 | 8.50 | 26.34 | 162.22 |
| 1418 | -28.50 | 10.50 | 28.74 | 159.77 |
| 1425 | -27.50 | 11.50 | 28.21 | 157.31 |
| 1430 | -36.00 | 20.00 | 38.98 | 150.95 |
| 1435 | -21.50 | 34.50 | 38.47 | 121.93 |
| 1441 | -6.50 | 19.50 | 19.45 | 108.43 |
| 1448 | -24.00 | 2.00 | 22.79 | 175.24 |
| 1457 | -38.00 | 16.00 | 39.02 | 157.17 |
| 1502 | -20.50 | 33.50 | 37.17 | 121.46 |
| 1508 | -1.50 | 14.50 | 13.80 | 95.91 |
| 1515 | -21.00 | -5.00 | 20.43 | 193.39 |
| 1522 | -38.00 | 12.00 | 37.71 | 162.47 |
| 1528 | -26.50 | 23.50 | 33.52 | 138.43 |
| 1533 | -15.50 | 12.50 | 18.84 | 141.12 |
| 1540 | -30.50 | -2.50 | 28.96 | 184.69 |
| 1549 | -45.50 | 12.50 | 44.66 | 164.64 |
| 1555 | -32.50 | 25.50 | 39.10 | 141.88 |
| 1601 | -15.50 | 8.50 | 16.73 | 151.26 |
| 1606 | -29.50 | -5.50 | 28.40 | 190.56 |
| 1613 | -38.50 | 3.50 | 36.59 | 174.81 |
| 1621 | -22.50 | 19.50 | 28.18 | 139.09 |
| 1625 | -13.50 | 10.50 | 16.19 | 142.12 |
| 1631 | -27.50 | -3.50 | 26.24 | 187.25 |
| 1639 | -38.00 | 7.00 | 36.57 | 169.56 |
| 1645 | -26.50 | 18.50 | 30.59 | 145.08 |
| 1649 | -18.00 | 10.00 | 19.49 | 150.95 |
| 1659 | -31.50 | -3.50 | 30.00 | 186.34 |
| 1709 | -42.50 | 7.50 | 40.84 | 169.99 |
| 1714 | -17.50 | 32.50 | 34.93 | 118.30 |

| C C TIME (PDT) | NORTH-SOUTH COMP(CM/SEC) | EAST-WEST COMP(CM/SEC) | MAGNITUDE (CM/SEC) | DIRECTION (DEG.TRUE) |
|---|---|---|---|---|
| 1719 | 10.00 | 5.00 | 10.58 | 26.57 |
| 1729 | -22.000 | -27.000 | 32.96 | 230.83 |
| 1738 | -47.500 | -1.500 | 44.98 | 181.81 |
| 1743 | -19.500 | 26.500 | 31.14 | 126.35 |
| 1748 | 17.000 | 0.000 | 6.62 | 360.00 |
| 1758 | -17.000 | -24.000 | 27.83 | 234.69 |
| 1808 | -41.000 | 0.000 | 38.80 | 180.00 |
| 1813 | -19.500 | 21.500 | 27.47 | 132.21 |
| 1819 | 3.000 | -1.000 | 2.99 | 341.56 |
| 1828 | -21.000 | -25.000 | 30.90 | 229.97 |
| 1838 | -38.000 | -8.000 | 36.75 | 191.89 |
| 1843 | -18.500 | 11.500 | 20.62 | 148.13 |
| 1848 | 1.000 | -8.000 | 7.63 | 277.12 |
| 1858 | -15.500 | -24.500 | 27.44 | 237.68 |
| 1908 | -31.000 | -9.000 | 30.55 | 196.19 |
| 1913 | -15.500 | 6.500 | 15.91 | 157.25 |
| 1918 | -2.000 | -7.000 | 6.89 | 254.05 |
| 1928 | -14.000 | -19.000 | 22.34 | 233.62 |
| 1938 | -25.000 | -8.000 | 24.84 | 197.74 |
| 1943 | -13.500 | 3.500 | 13.20 | 165.47 |
| 1948 | 0.000 | -10.000 | 9.46 | 270.00 |
| 1957 | -16.000 | -26.000 | 28.89 | 238.39 |
| 2006 | -25.000 | -17.000 | 28.61 | 214.22 |
| 2011 | -14.000 | -6.000 | 14.42 | 203.20 |
| 2016 | -3.000 | -17.000 | 16.34 | 259.99 |
| 2023 | -13.000 | -27.000 | 28.36 | 244.29 |
| 2031 | -24.000 | -16.000 | 27.30 | 213.69 |
| 2036 | -10.500 | -2.500 | 10.21 | 193.39 |
| 2042 | 3.500 | -16.500 | 15.96 | 281.98 |
| 2048 | -7.000 | -27.000 | 26.40 | 255.47 |
| 2054 | -12.500 | -21.500 | 23.54 | 239.83 |
| 2059 | -4.500 | -13.500 | 13.47 | 251.57 |
| 2105 | 7.000 | -25.000 | 24.57 | 285.64 |
| 2111 | 2.000 | -30.000 | 28.46 | 273.81 |
| 2118 | -4.000 | -24.000 | 23.03 | 260.54 |
| 2123 | -3.000 | -23.000 | 21.95 | 262.57 |
| 2128 | -0.500 | -25.500 | 24.14 | 268.88 |
| 2133 | -3.500 | -28.500 | 27.18 | 263.00 |
| 2140 | -9.500 | -22.500 | 23.11 | 247.11 |
| 2146 | -5.000 | -18.000 | 17.68 | 254.48 |
| 2151 | -1.000 | -22.000 | 20.84 | 267.40 |
| 2157 | -4.500 | -25.500 | 24.51 | 259.99 |
| 2203 | -3.000 | -27.000 | 25.71 | 263.66 |
| 2208 | 2.000 | -22.000 | 20.91 | 275.19 |
| 2213 | 5.00 | -25.00 | 24.13 | 281.31 |

| C C TIME (PDT) | NORTH-SOUTH COMP(CM/SEC) | EAST-WEST COMP(CM/SEC) | MAGNITUDE (CM/SEC) | DIRECTION (DEG.TRUE) |
|---|---|---|---|---|
| 2220 | 5.00 | -25.00 | 24.13 | 281.31 |
| 2227 | 4.50 | -24.50 | 23.57 | 280.41 |
| 2234 | 14.50 | -14.50 | 19.41 | 315.00 |
| 2239 | 24.00 | -24.00 | 32.12 | 315.00 |
| 2244 | 14.50 | -33.50 | 34.55 | 293.40 |
| 2250 | 3.00 | -22.00 | 21.01 | 277.76 |
| 2256 | 6.00 | -19.00 | 18.86 | 287.53 |
| 2301 | 4.00 | -17.00 | 16.53 | 283.24 |
| 2306 | 0.50 | -20.50 | 19.41 | 271.40 |
| 2313 | -3.00 | -17.00 | 16.34 | 259.99 |
| 2318 | 1.50 | -12.50 | 11.91 | 276.84 |
| 2323 | 6.00 | -17.00 | 17.06 | 289.44 |
| 2328 | 6.00 | -17.00 | 17.06 | 289.44 |
| 2333 | 9.50 | -20.50 | 21.38 | 294.86 |
| 2338 | 6.00 | -24.00 | 23.41 | 284.04 |
| 2343 | -1.00 | -17.00 | 16.12 | 266.63 |
| 2350 | 4.00 | -12.00 | 11.97 | 288.43 |
| 2356 | 6.00 | -14.00 | 14.42 | 293.20 |
| 2 | 4.50 | -15.50 | 15.27 | 286.19 |
| 8 | 6.00 | -17.00 | 17.06 | 289.44 |
| 14 | 7.00 | -16.00 | 16.53 | 293.63 |
| 18 | 11.50 | -20.50 | 22.25 | 299.29 |
| 23 | 7.50 | -24.50 | 24.25 | 287.02 |
| 28 | 1.50 | -18.50 | 17.57 | 274.64 |
| 34 | 6.50 | -13.50 | 14.18 | 295.71 |
| 39 | 8.50 | -15.50 | 16.73 | 298.74 |
| 44 | 4.00 | -20.00 | 19.30 | 281.31 |
| 50 | 2.00 | -18.00 | 17.14 | 276.34 |
| 56 | 5.50 | -14.50 | 14.68 | 290.77 |
| 102 | 8.00 | -17.00 | 17.78 | 295.20 |
| 108 | 5.50 | -19.50 | 19.17 | 285.75 |
| 112 | 3.50 | -17.50 | 16.89 | 281.31 |
| 116 | 5.00 | -16.00 | 15.86 | 287.35 |
| 121 | 7.00 | -18.00 | 18.28 | 291.25 |
| 126 | 7.00 | -18.00 | 18.28 | 291.25 |
| 131 | 7.00 | -18.00 | 18.28 | 291.25 |
| 136 | 7.00 | -18.00 | 18.28 | 291.25 |
| 141 | 9.00 | -20.00 | 20.76 | 294.23 |
| 147 | 7.00 | -22.00 | 21.85 | 287.65 |
| 151 | 2.50 | -17.50 | 16.73 | 278.13 |
| 156 | 0.0 | -20.00 | 18.93 | 270.00 |
| 201 | -5.00 | -15.00 | 14.96 | 251.57 |
| 206 | -3.00 | -13.00 | 12.63 | 257.01 |
| 211 | -1.00 | -15.00 | 14.23 | 266.19 |
| 216 | -5.50 | -19.50 | 19.17 | 254.25 |

| C C TIME (PDT) | NORTH-SOUTH COMP(CM/SEC) | EAST-WEST COMP(CM/SEC) | MAGNITUDE (CM/SEC) | DIRECTION (DEG.TRUE) |
|---|---|---|---|---|
| 221 | -6.50 | -18.50 | 18.56 | 250.64 |
| 226 | -6.50 | -18.50 | 18.56 | 250.64 |
| 244 | 7.00 | -7.00 | 9.36 | 315.00 |
| 250 | 7.50 | -6.50 | 9.39 | 319.09 |
| 256 | 6.50 | -5.50 | 8.06 | 319.76 |
| 301 | 1.50 | -10.50 | 10.04 | 278.13 |
| 306 | 10.50 | -19.50 | 20.96 | 298.30 |
| 310 | 22.50 | -7.50 | 22.45 | 341.56 |
| 315 | 12.50 | 2.50 | 12.06 | 11.31 |
| 321 | 5.00 | -5.00 | 6.69 | 315.00 |
| 326 | 10.50 | -10.50 | 14.05 | 315.00 |
| 331 | 16.00 | -5.00 | 15.86 | 342.65 |
| 336 | 13.50 | -2.50 | 12.99 | 349.51 |
| 341 | 18.50 | 2.50 | 17.67 | 7.70 |
| 346 | 18.00 | 3.00 | 17.27 | 9.46 |
| 351 | 17.50 | 2.50 | 16.73 | 8.13 |
| 357 | 21.50 | -1.50 | 20.40 | 356.01 |
| 402 | 22.00 | -1.00 | 20.84 | 357.40 |
| 407 | 20.50 | 0.50 | 19.41 | 1.40 |
| 412 | 22.50 | 2.50 | 21.43 | 6.34 |
| 417 | 15.50 | 9.50 | 17.21 | 31.50 |
| 422 | 7.00 | 1.00 | 6.69 | 8.13 |
| 427 | 13.50 | -5.50 | 13.80 | 337.83 |
| 433 | 24.00 | 5.00 | 23.20 | 11.77 |
| 438 | 13.50 | 15.50 | 19.45 | 48.95 |
| 443 | 8.00 | 10.00 | 12.12 | 51.34 |
| 448 | 8.50 | 9.50 | 12.06 | 48.18 |
| 452 | 10.50 | 11.50 | 14.74 | 47.60 |
| 457 | 10.50 | 11.50 | 14.74 | 47.60 |
| 502 | 13.00 | 14.00 | 18.08 | 47.12 |
| 507 | 8.50 | 18.50 | 19.27 | 65.32 |
| 512 | 5.00 | 15.00 | 14.96 | 71.57 |
| 517 | 4.50 | 15.50 | 15.27 | 73.81 |
| 522 | 8.50 | 19.50 | 20.13 | 66.45 |
| 527 | 2.00 | 26.00 | 24.68 | 85.60 |
| 532 | -2.50 | 21.50 | 20.48 | 96.63 |
| 537 | -0.50 | 19.50 | 18.46 | 91.47 |
| 543 | 1.00 | 21.00 | 19.90 | 87.27 |
| 548 | 2.00 | 20.00 | 19.02 | 84.29 |
| 552 | 6.00 | 24.00 | 23.41 | 75.96 |
| 558 | 1.00 | 29.00 | 27.46 | 88.02 |
| 603 | -5.50 | 22.50 | 21.92 | 103.74 |
| 609 | 0.50 | 16.50 | 15.62 | 88.26 |
| 614 | 4.00 | 20.00 | 19.30 | 78.69 |
| 620 | -4.00 | 28.00 | 26.77 | 98.13 |

| C C TIME (PDT) | NORTH-SOUTH COMP(CM/SEC) | EAST-WEST COMP(CM/SEC) | MAGNITUDE (CM/SEC) | DIRECTION (DEG.TRUE) |
|---|---|---|---|---|
| 626 | -10.50 | 21.50 | 22.64 | 116.03 |
| 631 | -3.50 | 14.50 | 14.12 | 103.57 |
| 639 | 3.50 | 21.50 | 20.62 | 80.75 |
| 644 | -4.00 | 29.00 | 27.71 | 97.85 |
| 649 | -12.50 | 20.50 | 22.72 | 121.37 |
| 654 | -15.00 | 23.00 | 25.99 | 123.11 |
| 700 | -14.50 | 23.50 | 26.13 | 121.68 |
| 710 | -12.50 | 21.50 | 23.54 | 120.17 |
| 715 | -12.00 | 22.00 | 23.72 | 118.61 |
| 720 | -12.50 | 22.50 | 24.36 | 119.05 |
| 725 | -13.00 | 22.00 | 24.18 | 120.58 |
| 733 | -15.00 | 24.00 | 26.78 | 122.01 |
| 738 | -18.00 | 21.00 | 26.18 | 130.60 |
| 743 | -17.00 | 20.00 | 24.84 | 130.36 |
| 748 | -19.00 | 18.00 | 24.77 | 136.55 |
| 753 | -20.50 | 19.50 | 26.78 | 136.43 |
| 802 | -18.00 | 22.00 | 26.90 | 129.29 |
| 807 | -19.50 | 23.50 | 28.90 | 129.69 |
| 812 | -21.00 | 22.00 | 28.78 | 133.67 |
| 818 | -14.50 | 15.50 | 20.09 | 133.09 |
| 823 | -11.00 | 19.00 | 20.78 | 120.07 |
| 829 | -13.50 | 21.50 | 24.03 | 122.12 |
| 833 | -16.00 | 19.00 | 23.51 | 130.10 |
| 840 | -13.50 | 16.50 | 20.18 | 129.29 |
| 845 | -13.50 | 16.50 | 20.18 | 129.29 |
| 857 | -13.50 | 19.50 | 22.45 | 124.70 |
| 903 | -16.50 | 16.50 | 22.08 | 135.00 |
| 909 | -16.50 | 16.50 | 22.08 | 135.00 |
| 916 | -14.00 | 19.00 | 22.34 | 126.38 |
| 921 | -20.50 | 25.50 | 30.96 | 128.80 |
| 927 | -27.00 | 19.00 | 31.25 | 144.87 |
| 933 | -20.50 | 12.50 | 22.72 | 148.63 |
| 939 | -17.00 | 16.00 | 22.09 | 136.74 |
| 945 | -15.50 | 14.50 | 20.09 | 136.91 |
| 950 | -14.50 | 15.50 | 20.09 | 133.09 |
| 956 | -10.00 | 11.00 | 14.07 | 132.27 |
| 1003 | -4.00 | 17.00 | 16.53 | 103.24 |
| 1013 | -10.00 | 23.00 | 23.74 | 113.50 |
| 1018 | -15.50 | 17.50 | 22.12 | 131.53 |
| 1023 | -13.00 | 15.00 | 18.79 | 130.91 |
| 1029 | -8.50 | 19.50 | 20.13 | 113.55 |
| 1039 | -9.00 | 20.00 | 20.76 | 114.23 |
| 1044 | -9.00 | 20.00 | 20.76 | 114.23 |
| 1049 | -4.00 | 15.00 | 14.69 | 104.93 |
| 1056 | -2.00 | 17.00 | 16.20 | 96.71 |

| C C TIME (PDT) | NORTH-SOUTH COMP(CM/SEC) | EAST-WEST COMP(CM/SEC) | MAGNITUDE (CM/SEC) | DIRECTION (DEG.TRUE) |
|---|---|---|---|---|
| 1102 | -4.00 | 19.00 | 18.38 | 101.89 |
| 1108 | -10.50 | 12.50 | 15.45 | 130.03 |
| 1113 | -3.50 | 5.50 | 6.17 | 122.47 |
| 1120 | 11.00 | 20.00 | 21.60 | 61.19 |
| 1125 | -0.50 | 31.50 | 29.82 | 90.91 |
| 1132 | -7.50 | 24.50 | 24.25 | 107.02 |
| 1137 | -5.00 | 22.00 | 21.35 | 102.80 |
| 1145 | -4.50 | 22.50 | 21.72 | 101.31 |
| 1150 | -7.00 | 25.00 | 24.57 | 105.64 |
| 1157 | -10.50 | 21.50 | 22.64 | 116.03 |
| 1201 | -5.50 | 16.50 | 16.46 | 108.43 |
| 1208 | -2.00 | 20.00 | 19.02 | 95.71 |
| 1214 | -7.50 | 25.50 | 25.16 | 106.39 |
| 1220 | -12.50 | 20.50 | 22.72 | 121.37 |
| 1225 | -4.50 | 12.50 | 12.57 | 109.80 |
| 1229 | 1.50 | 18.50 | 17.57 | 85.36 |
| 1234 | -2.00 | 22.00 | 20.91 | 95.19 |
| 1239 | -2.00 | 22.00 | 20.91 | 95.19 |

# APPENDIX C

## UNAVERAGED CURRENT DATA PLOTTED VERSUS WINDS AND TIDES

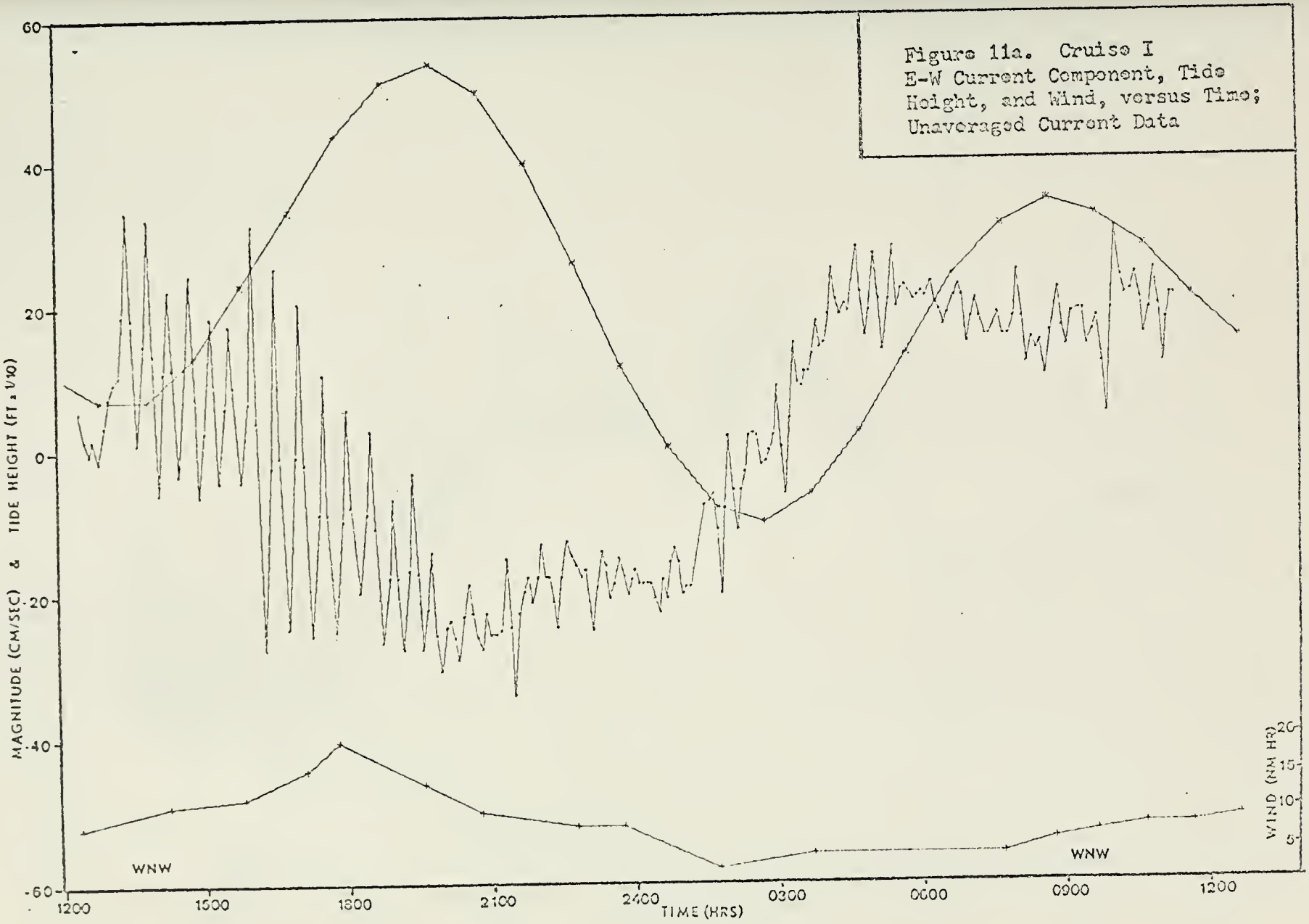


Figure 11a. Cruise I
E-W Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

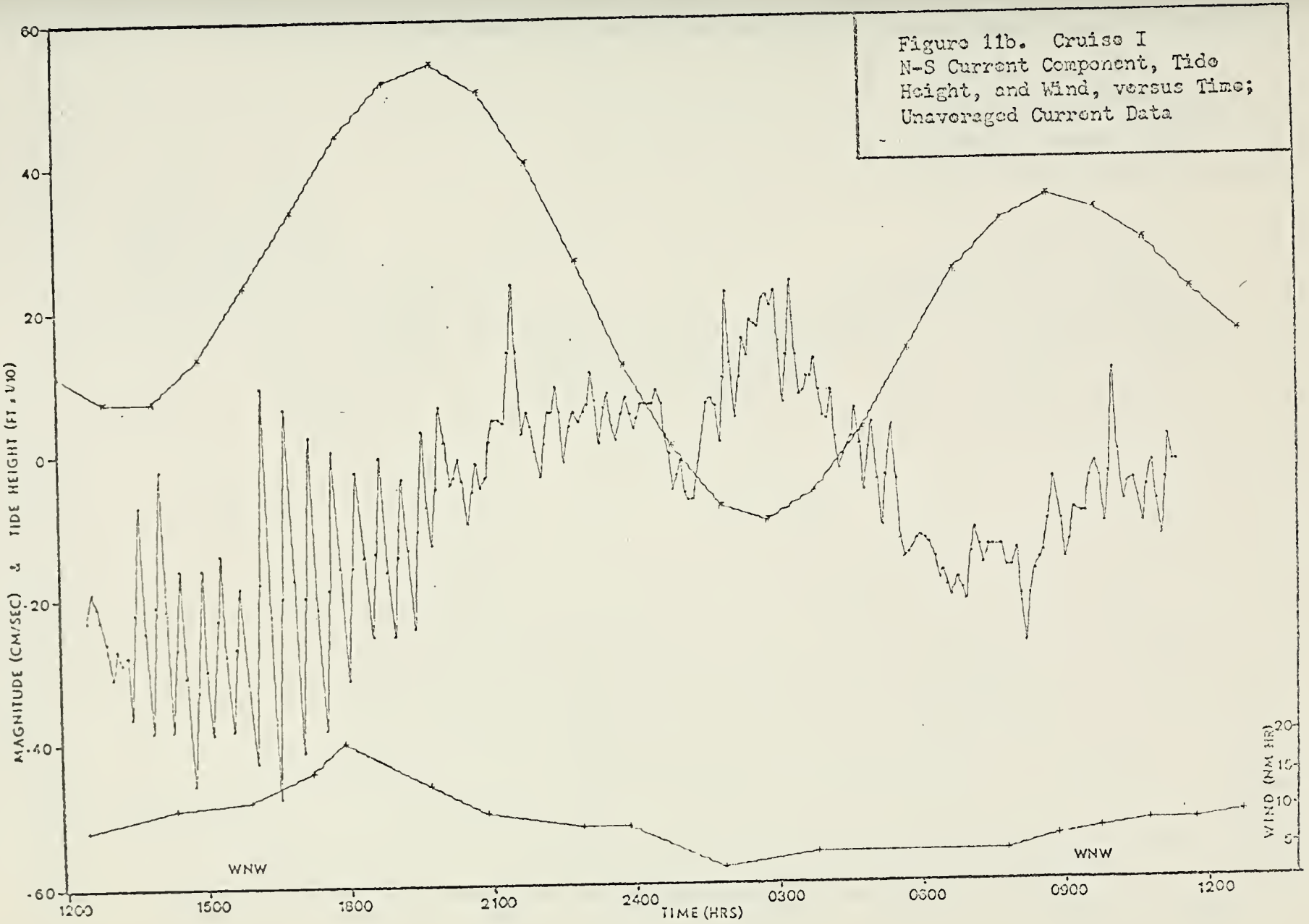


Figure 11b. Cruise I
N-S Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

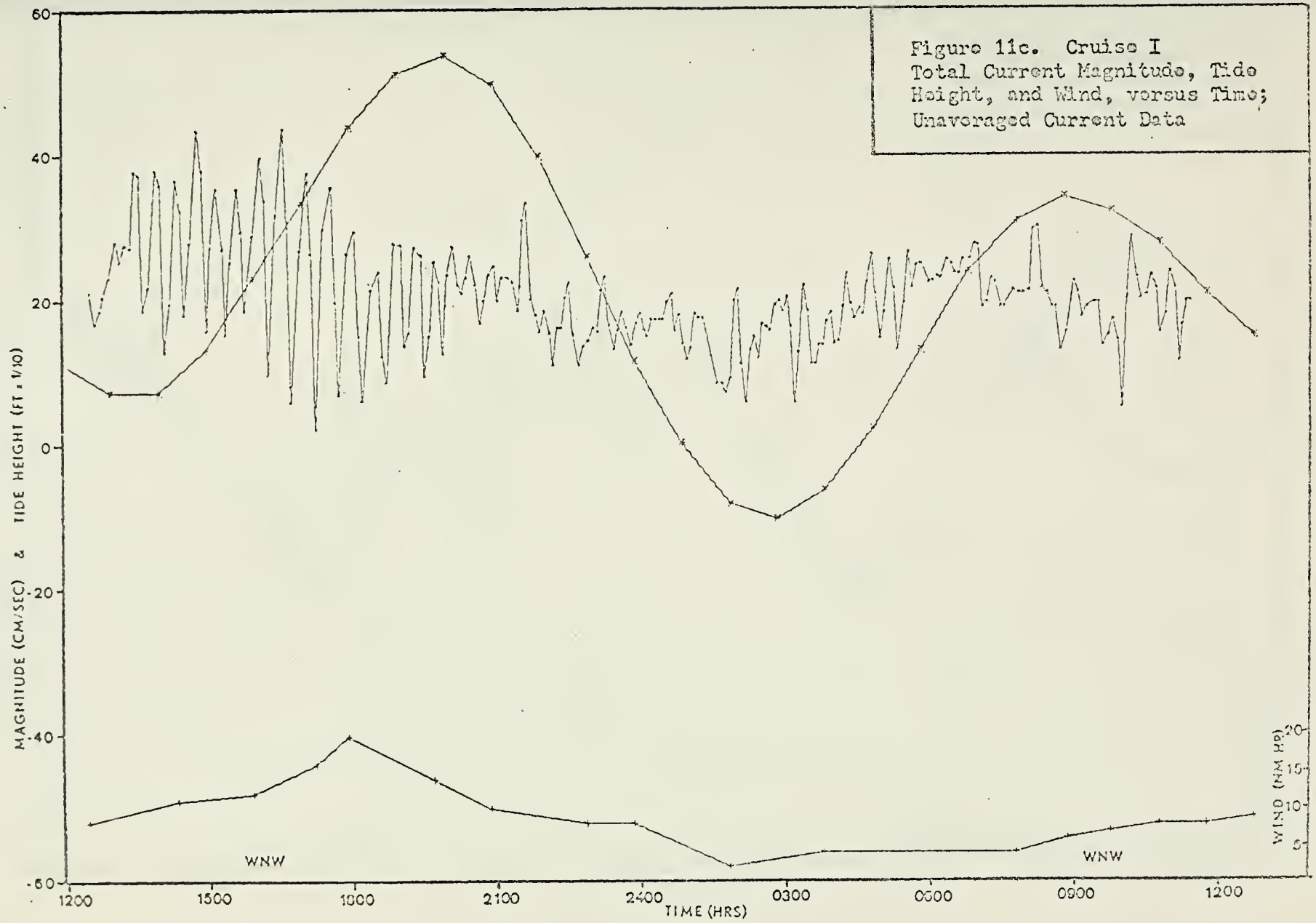


Figure 11c. Cruise I
Total Current Magnitude, Tide Height, and Wind, versus Time; Unaveraged Current Data

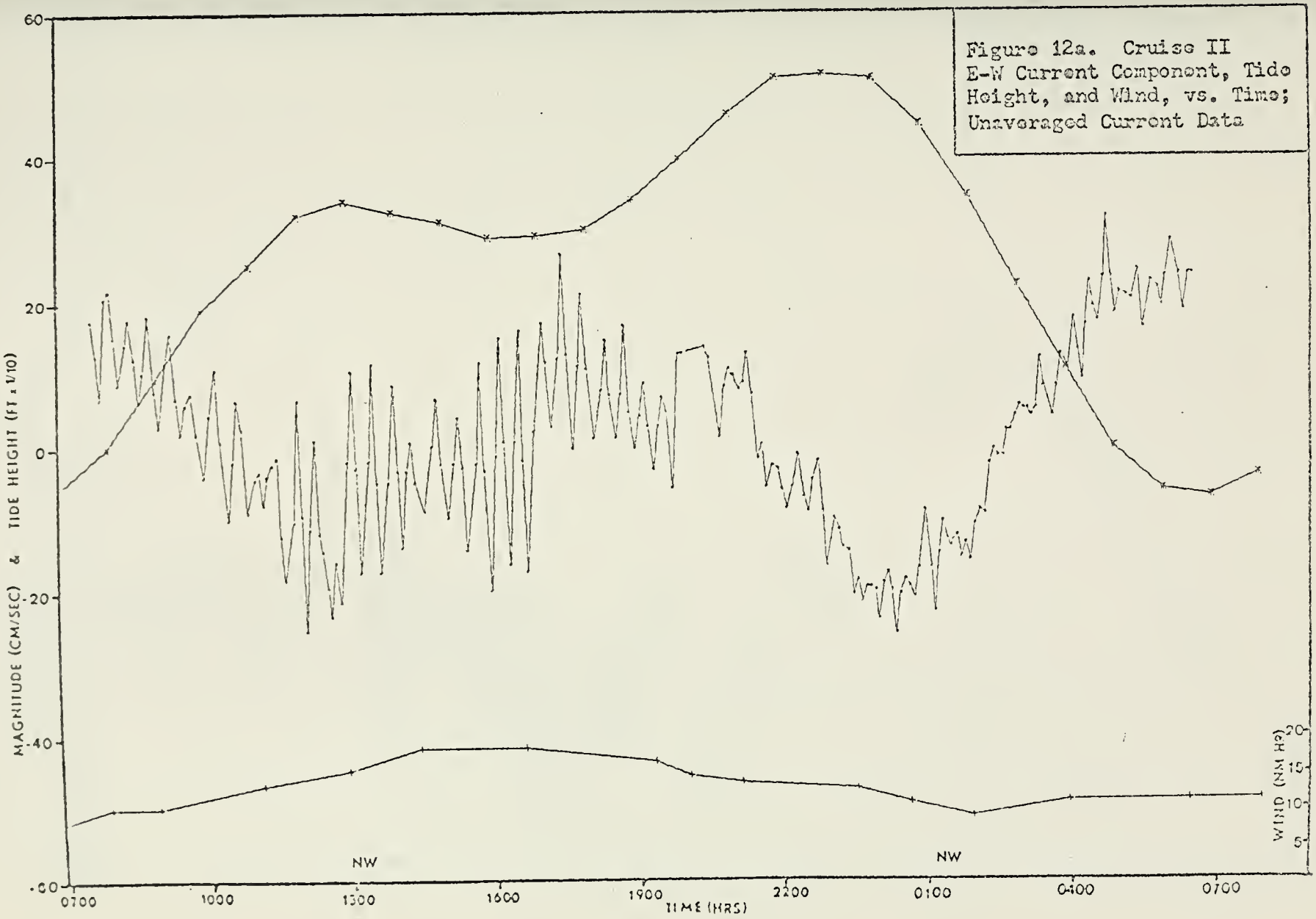


Figure 12a. Cruise II
E-W Current Component, Tide Height, and Wind, vs. Time; Unaveraged Current Data

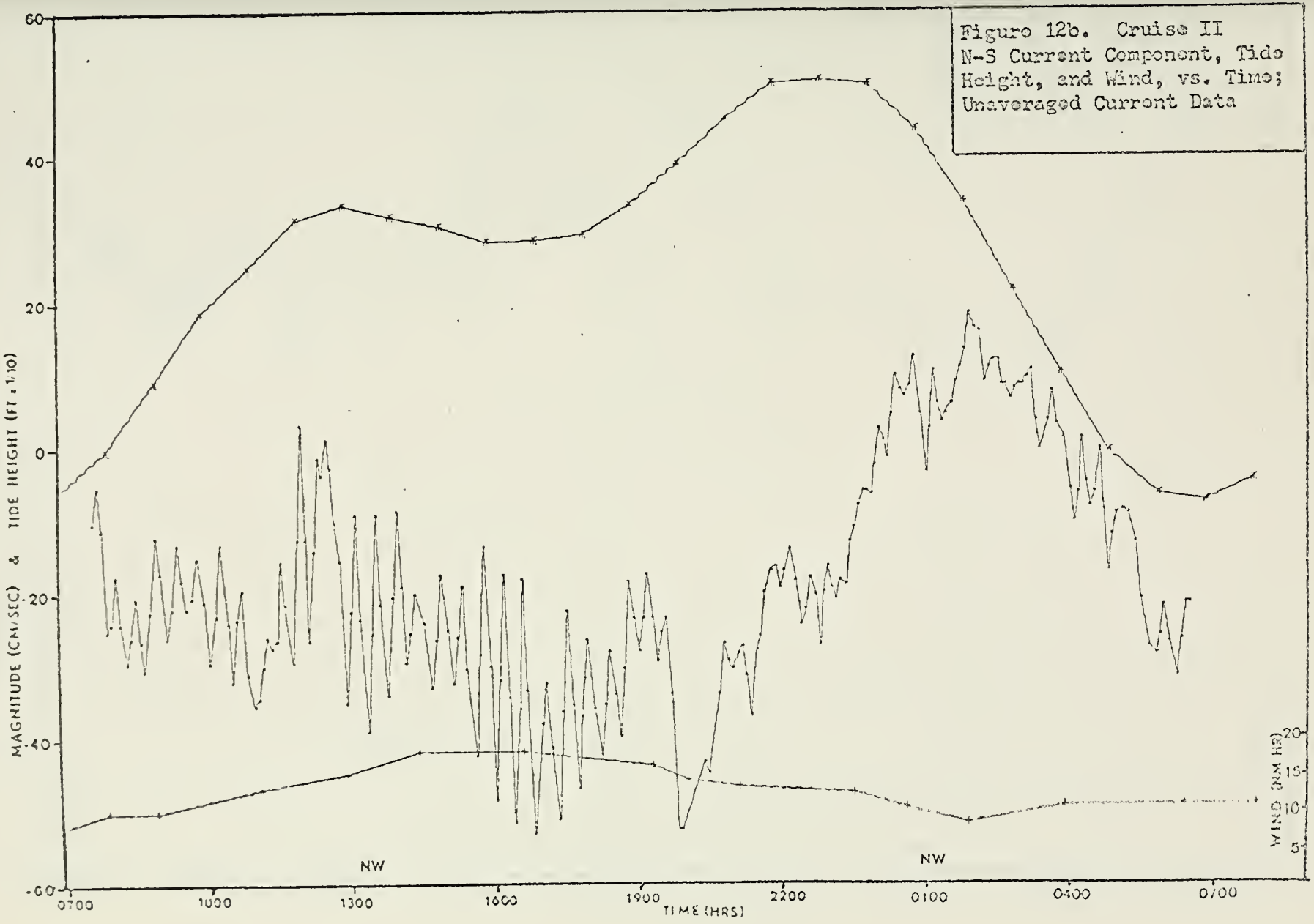


Figure 12b. Cruise II
N-S Current Component, Tide Height, and Wind, vs. Time; Unaveraged Current Data

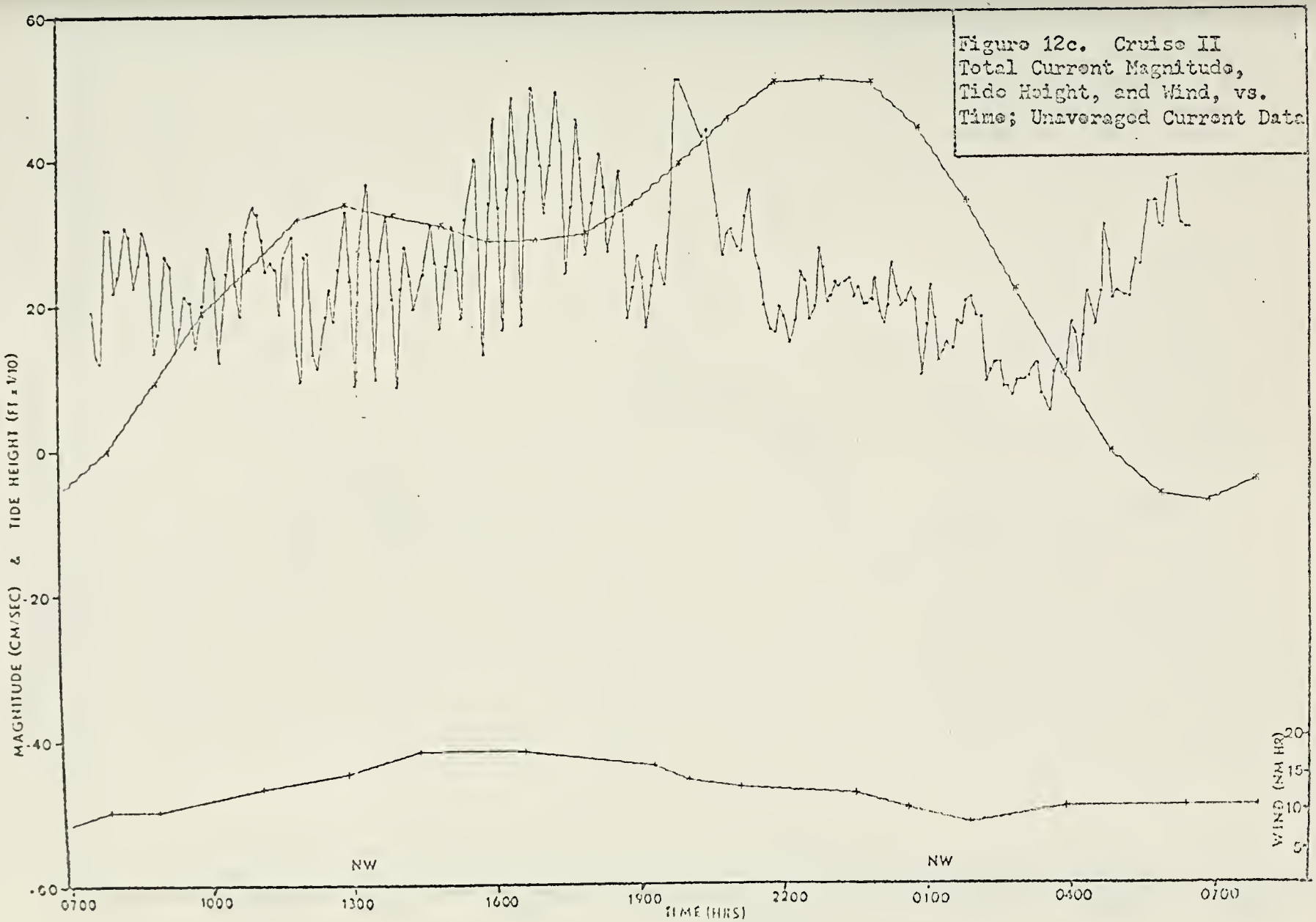


Figure 12c. Cruise II
Total Current Magnitude,
Tide Height, and Wind, vs.
Time; Unaveraged Current Data

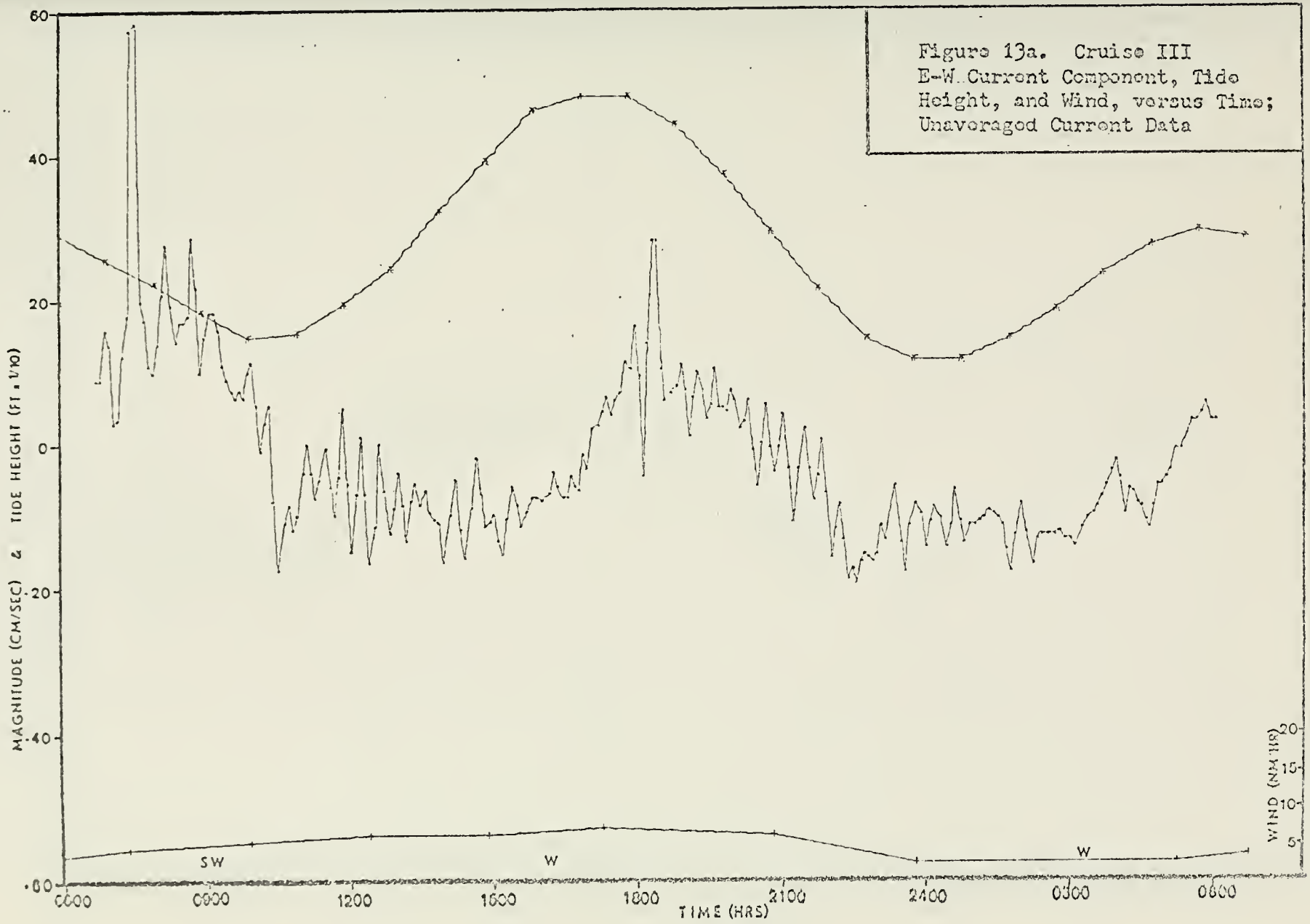


Figure 13a. Cruise III
E-W Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

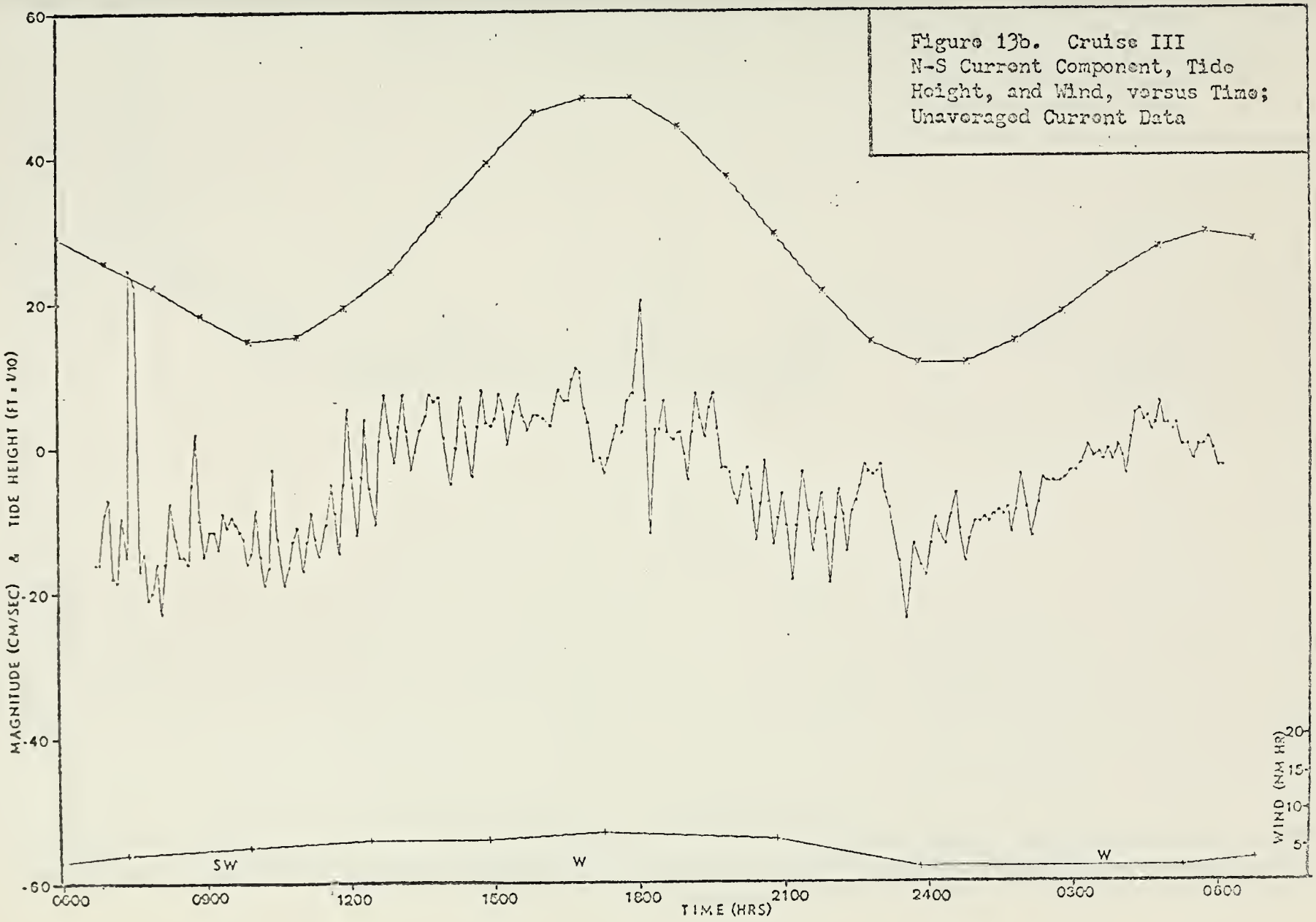


Figure 13b. Cruise III
N-S Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

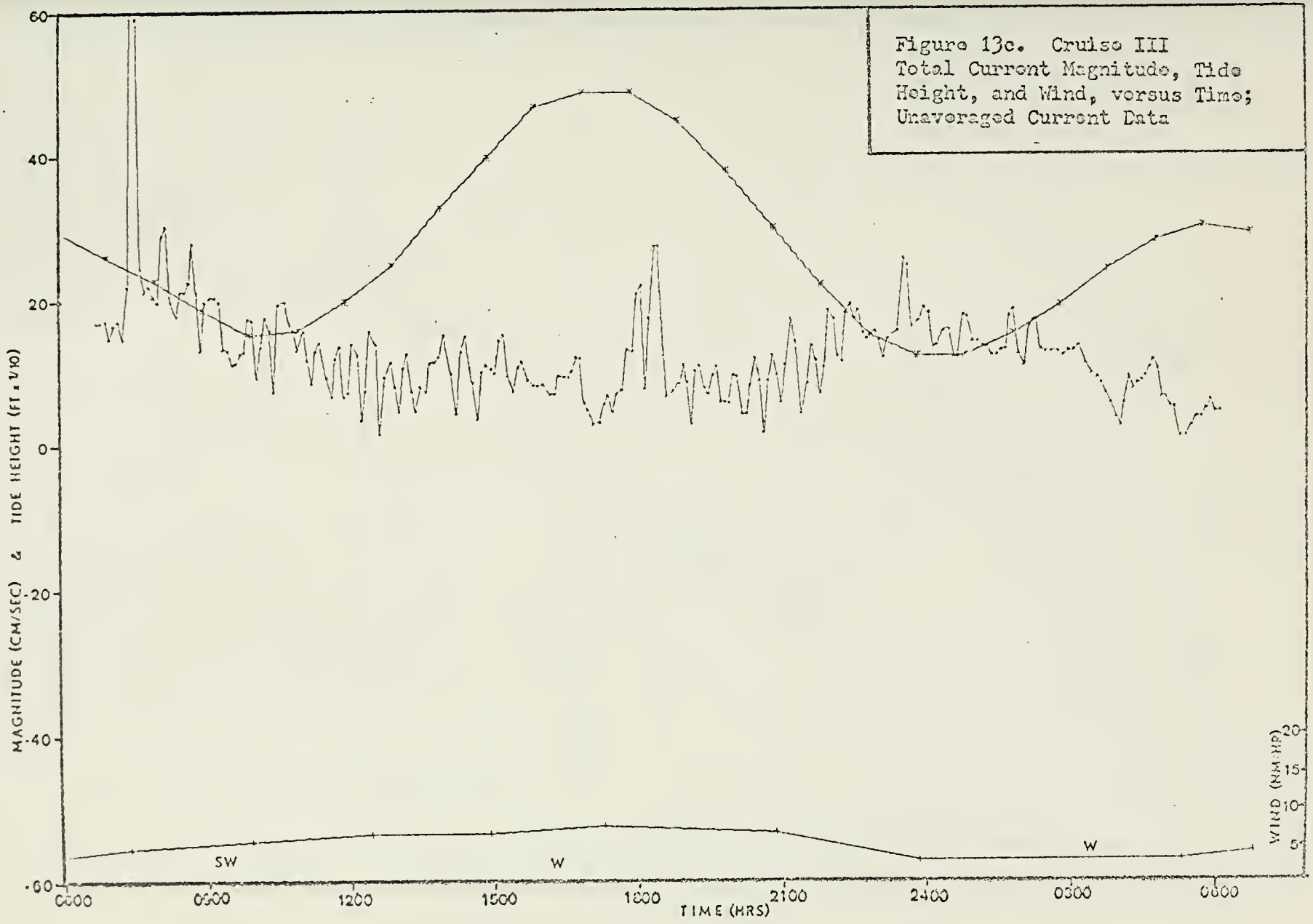


Figure 13c. Cruise III
Total Current Magnitude, Tide Height, and Wind, versus Time; Unaveraged Current Data

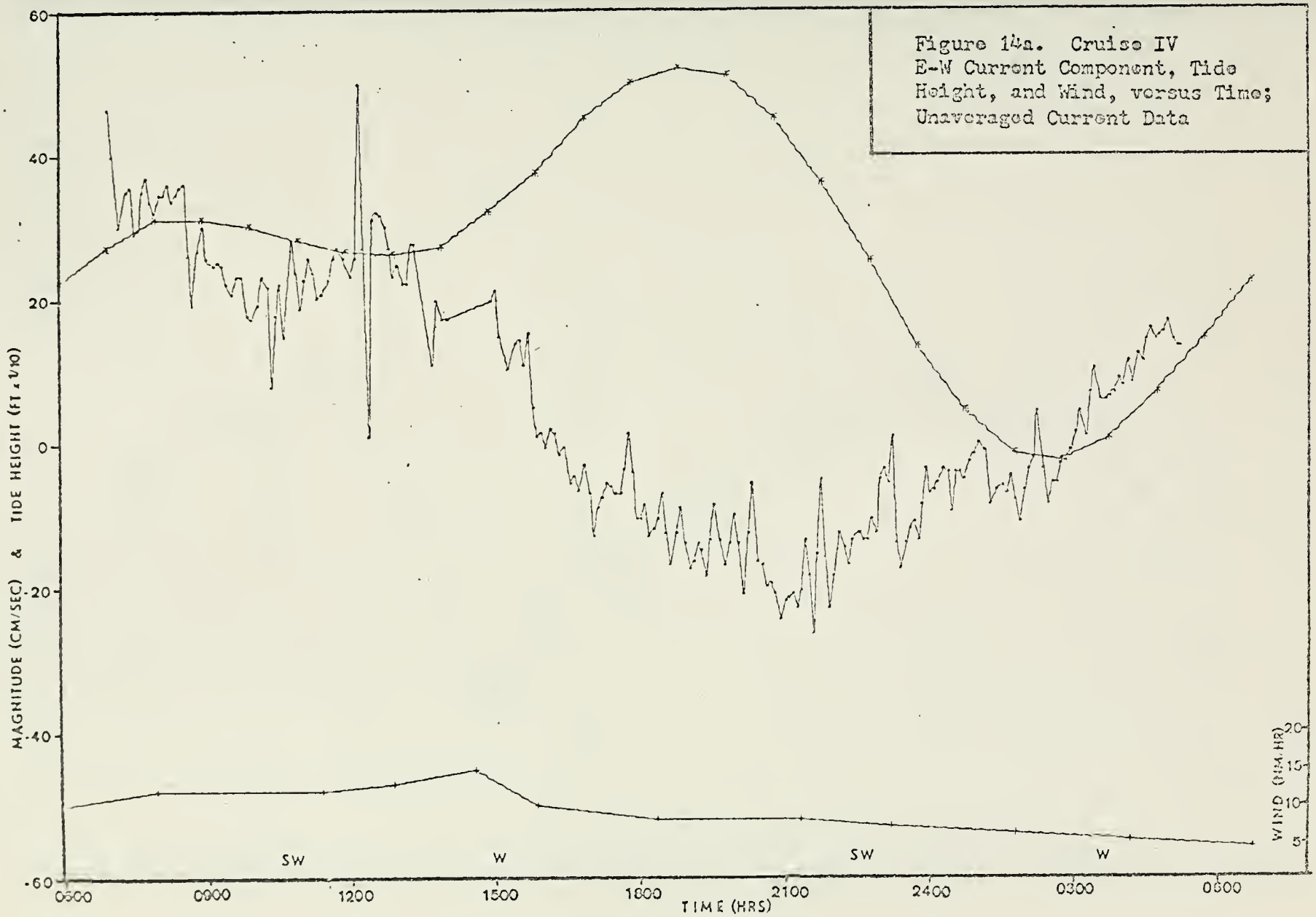
Figure 14a. Cruise IV
E-W Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data
MAGNITUDE (CM/SEC) & TIDE HEIGHT (FT x 1/10)
60
40
20
0
-20
-40
-60
SW
W
SW
W
0300
0900
1200
1500
1800
2100
2400
0300
0600
TIME (HRS)
WIND (KNOTS)
20
15
10
5

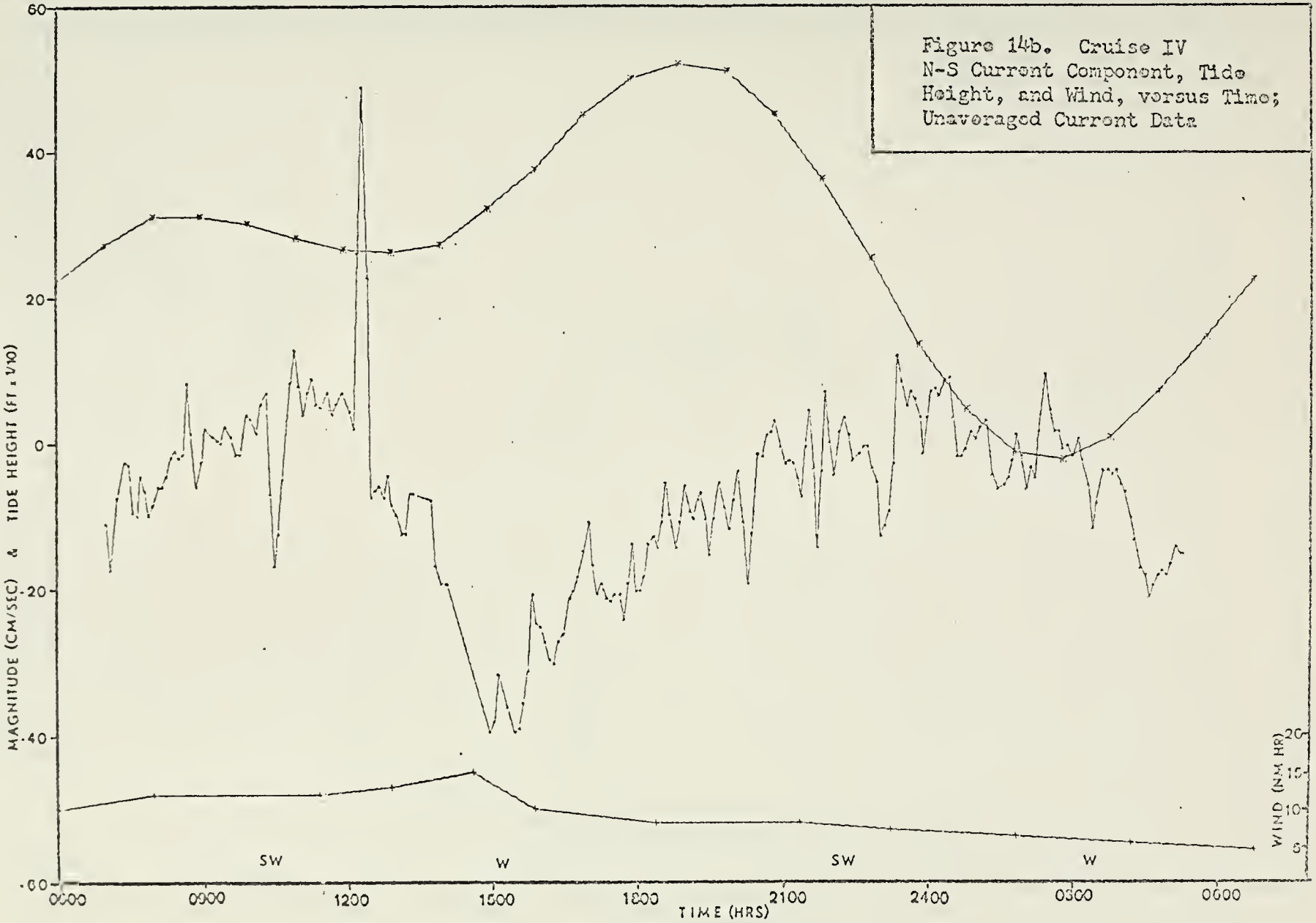


Figure 14b. Cruise IV
N-S Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

Figure 14c. Cruise IV
Total Current Magnitude, Tide Height, and Wind, versus Time; Unaveraged Current Data

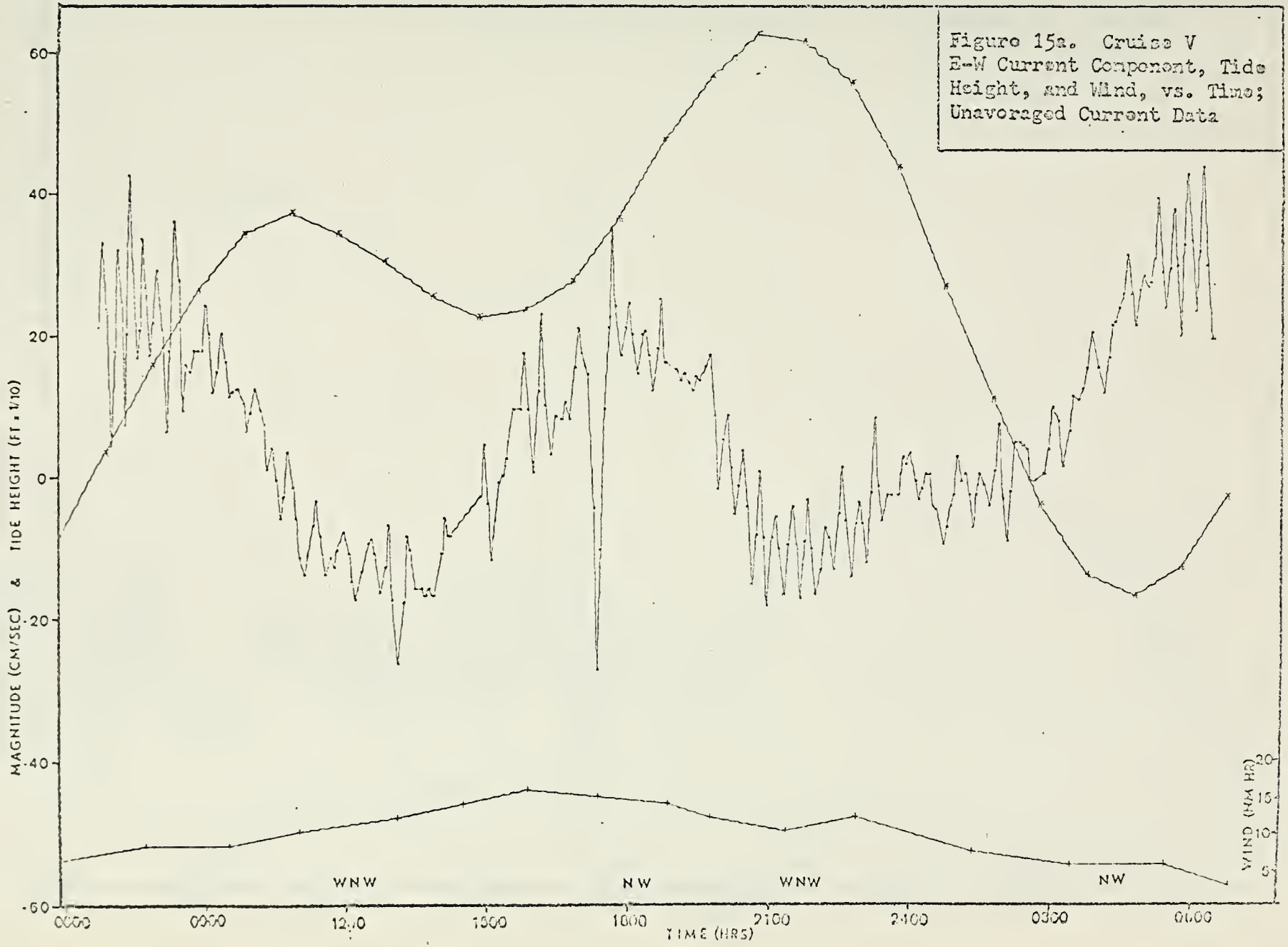
Figure 15a. Cruise V
E-W Current Component, Tide Height, and Wind, vs. Time; Unaveraged Current Data
MAGNITUDE (CM/SEC) & TIDE HEIGHT (FT x 1/10)
60
40
20
0
-20
-40
-60
WNW
NW
WNW
NW
WIND (KNOTS)
20
15
10
5
0000
0300
1200
1500
1800
2100
2400
0300
0600
TIME (HRS)

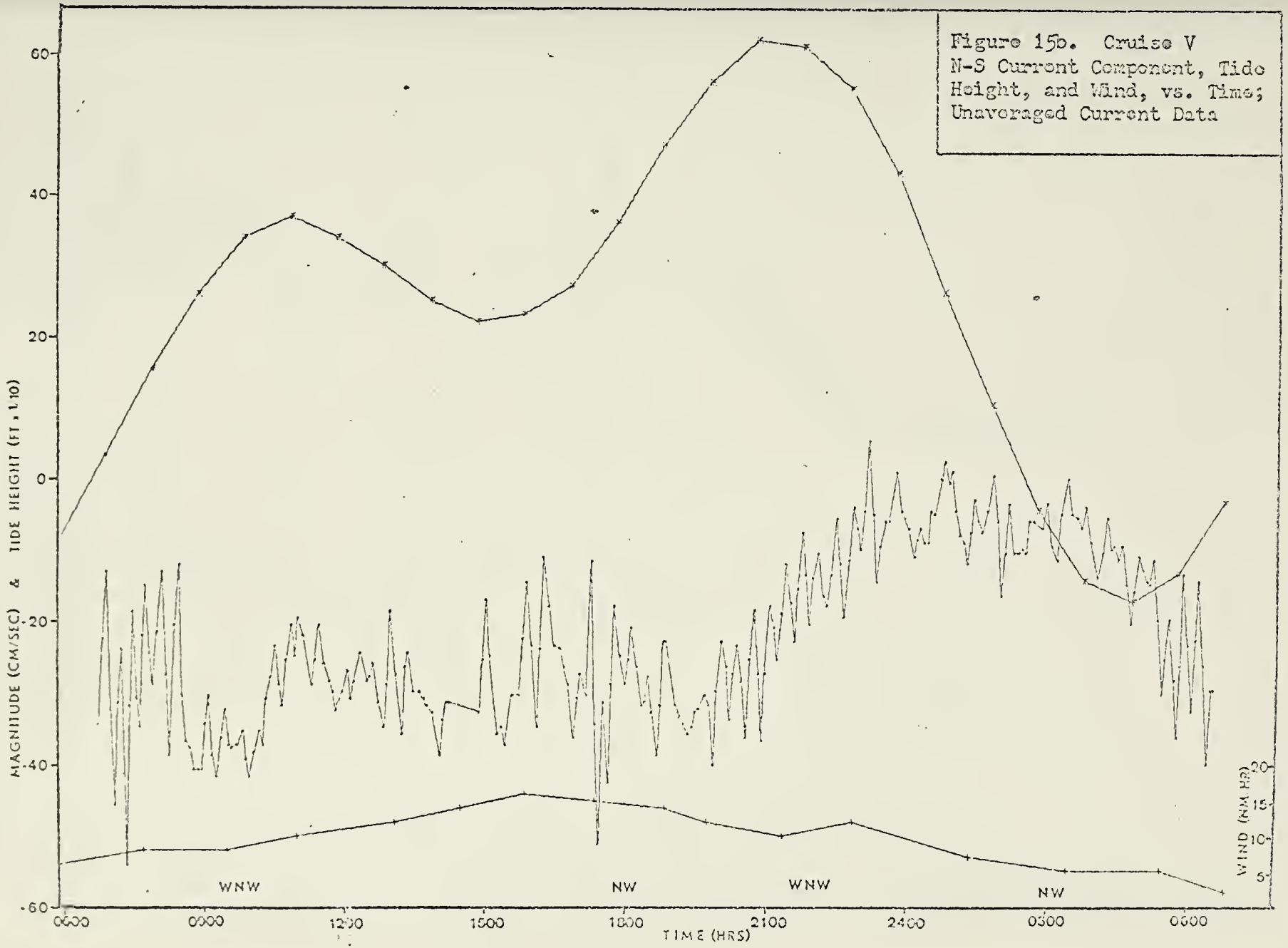


Figure 15b. Cruise V
N-S Current Component, Tide Height, and Wind, vs. Time; Unaveraged Current Data

Figure 15c. Cruise V
Total Current Magnitude,
Tide Height, and Wind, vs.
Time; Unaveraged Current Data
MAGNITUDE (CM/SEC) & TIDE HEIGHT (FT. X 1/10)
60
40
20
0
-20
-40
-60
WNW
NW
WNW
NW
WIND (KNOTS)
20
15
10
5
0000
0300
1200
1500
1800
2100
2400
0300
0600
TIME (HRS)

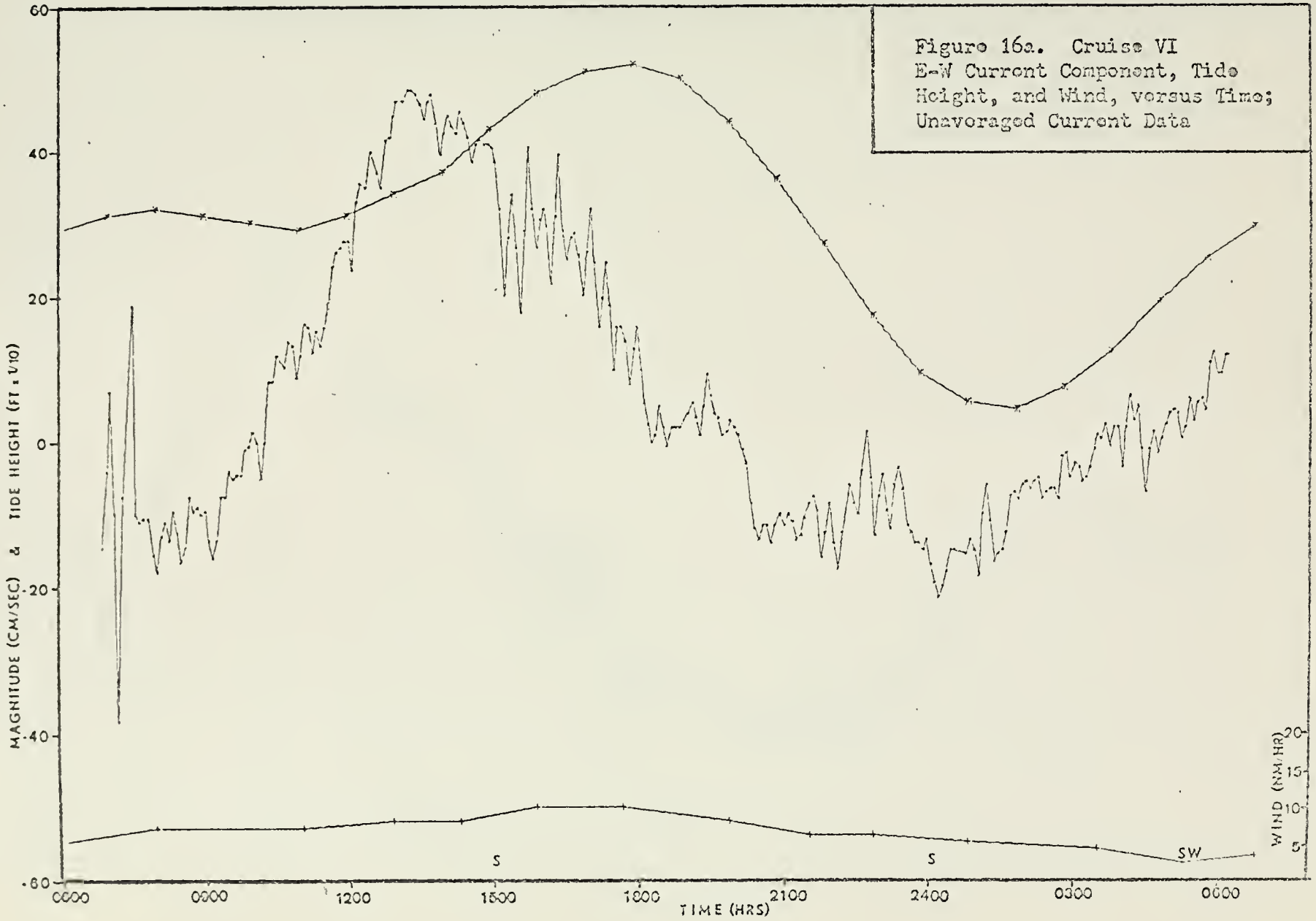


Figure 16a. Cruise VI
E-W Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

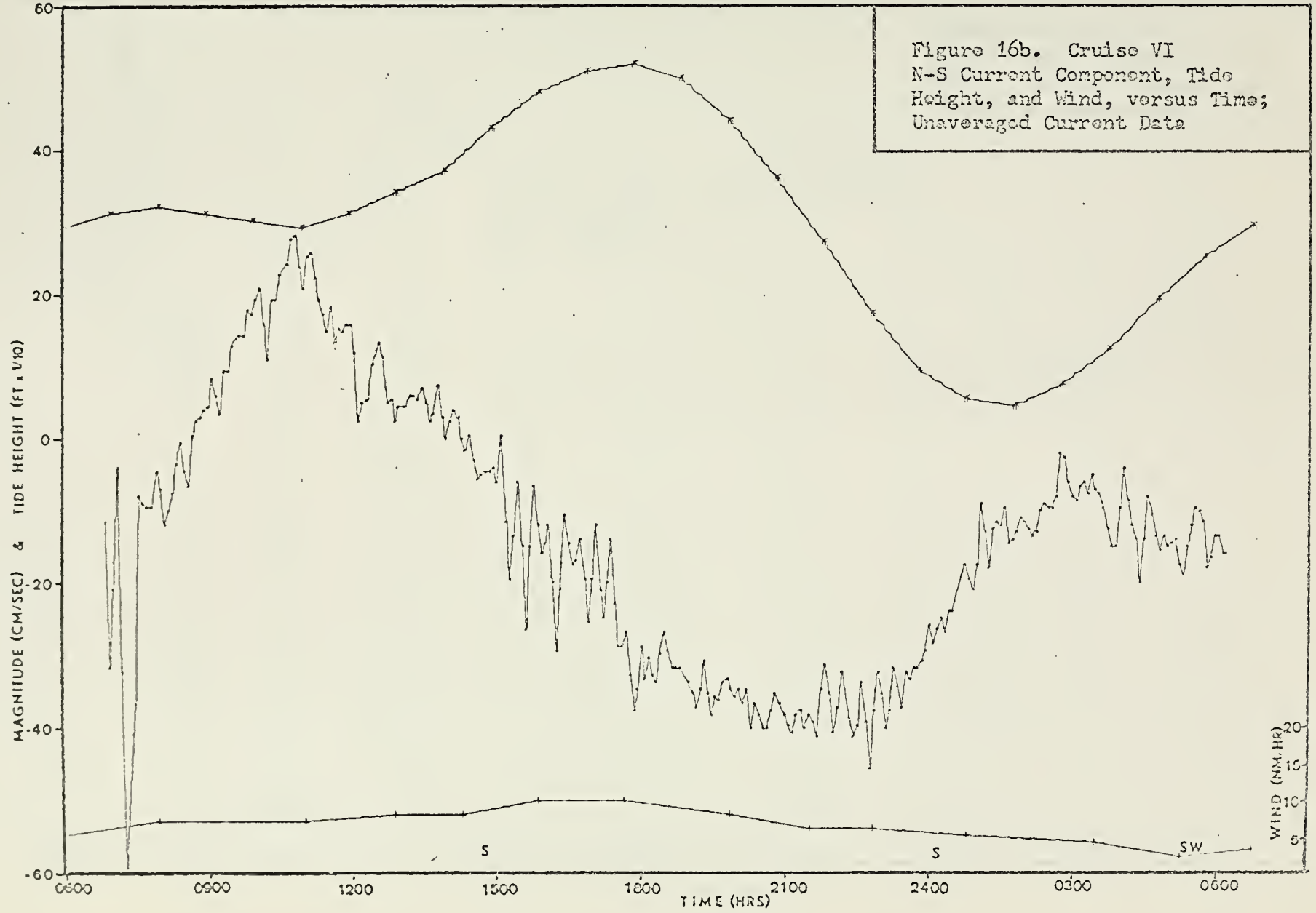


Figure 16b. Cruise VI
N-S Current Component, Tide Height, and Wind, versus Time; Unaveraged Current Data

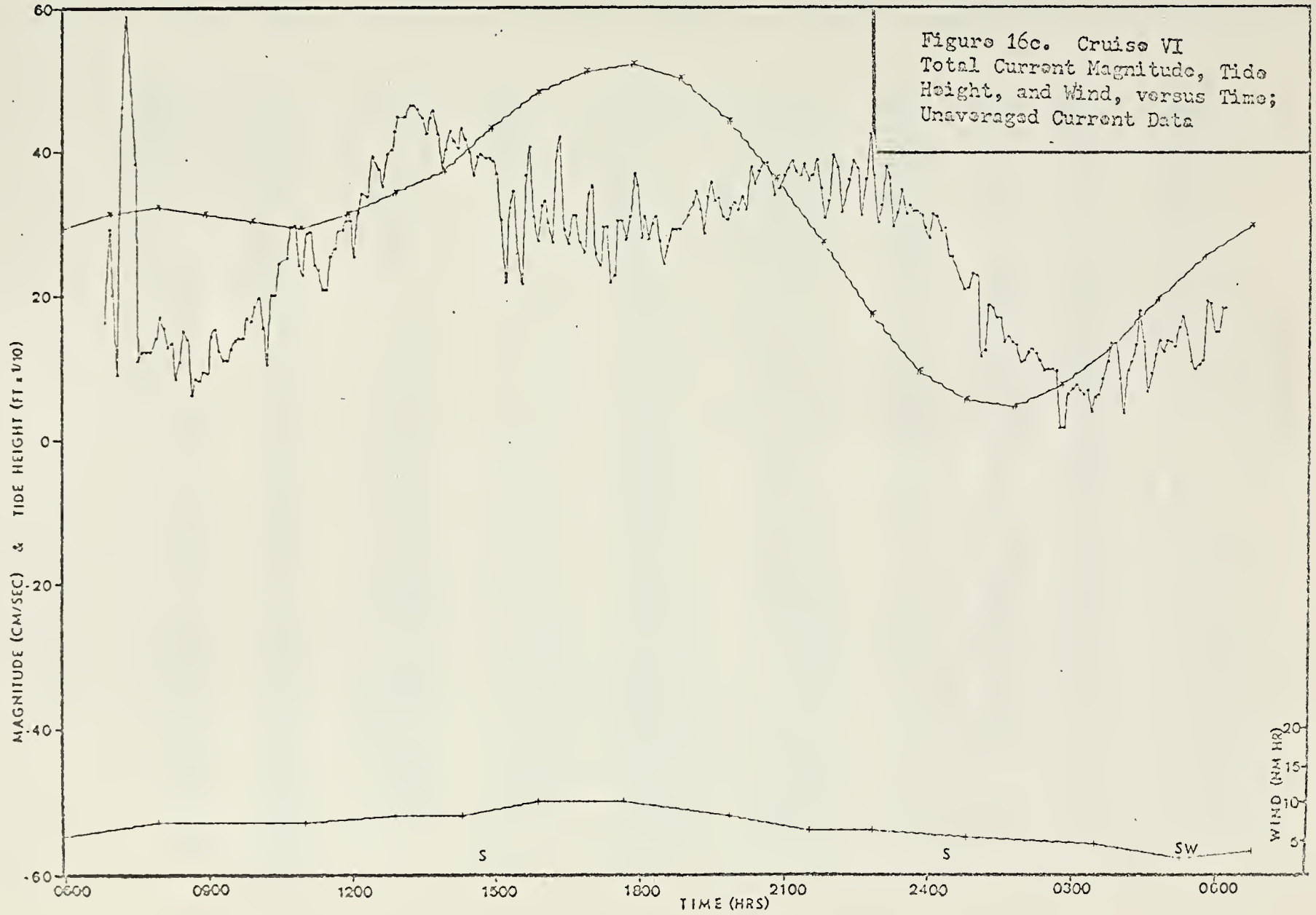


Figure 16c. Cruise VI
Total Current Magnitude, Tide Height, and Wind, versus Time; Unaveraged Current Data

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BSTRACT

The geomagnetic electrokinetograph (GEK) was used to measure surface currents
ar the center of Monterey Bay during six separate 24-hour periods from May through
y, 1972. An average of 244 current vectors were derived for each cruise. The mean
rrents from these cruises are all southerly and ranged from 4.1 cm/sec to 20.4 cm/sec.
e average of these mean currents is 12.1 cm/sec toward 163°T. These values were
mpared with individual currents derived from dynamic topographies from the same
riod. Diurnal and semi-diurnal variations of the current were studied after subjecting
e data to a fourier analysis. It was concluded that there must be at least an indirect
upling of the ocean currents with the semi-diurnal tide at the data point. The diurnal
mponent also is important; it may be tidal or inertial, or merely related to the passage
the sun.

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